MODELLING CRITICAL GAPS FOR U-TURN VEHICLES AT MEDIAN OPENINGS UNDER INDIAN MIXED TRAFFIC CONDITIONS

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This thesis is dedicated

To the my Father and beloved Mother,
May God bless them and elongate them live in his obedience.

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ABSTRACT

Establishment of un-signalized median openings have expanded in numerous urban districts of cities in India. The thought process behind this establishment is to take out issues connected with illicit U-turns occurring at crossing points and other transportation facilities near these median openings on multi-lane urban streets. Gap Acceptance concept of U-turn drivers is an imperative angle at un-signalized median openings for deciding limit of accidents. Critical Gap structures the sole parameter in Gap acceptance models for assessing U-turns at median openings. Estimation of critical gaps for U-turn vehicles at median openings under mixed traffic conditions have not been addressed until today. The explanation for this carelessness is the complex vehicular associations and dangerous path changing operations by non-motorized vehicles at these facilities. So as to take care of this issue and to address the blended/ mixed traffic conditions in India critical gaps were assessed utilizing a few Gap acceptance models with a point of evaluating limit of these U-turns at median openings. Information gathered for this study is in the form of video-image processing/recording of nine bi-directional-mid-block median openings on 4-lane and 6-lane roads without left-turn lanes placed in the urban areas of Bhubaneshwar and Rourkela located in the eastern part of India. The study focuses our consideration towards advancement of another idea on uniting conduct of U-turn vehicles for assessment of critical gaps acknowledged by U-turn drivers focused around the "INAFOGA" strategy. Existing routines display in past studies like Harders methods, Modified Raff method, Macroscopic Probability Equilibrium technique, Ashworth's model, Cumulative Gap Acceptance model and "INAFOGA" techniques were used for critical gap estimation. To record for the heterogeneous/blended movement conditions in India a few classes of motorized modes of transportation are acknowledged. Motorized modes, for example, three wheelers (four-stroke auto rickshaws and conveyance vans), light business vehicles (4 wheeler beats), diverse models of cars to be specific Sedans, Hatchbacks and Sport utility vehicles (SUVs/MUVs) are recognized as examples for U-turn movement. Conflicting/through movement contained Heavy vehicles like Busses, Lorries and trucks with multi- axles including the above classifications. Non-motorized vehicles like bi-cycles, pedal-rickshaws and pedestrian samples were rejected because of their lacking and irregular behaviour at the chosen sites under blended traffic manoeuvres. After feature recording vital choice variables were concentrated according to the new idea of merging behaviour

of U-turns ("INAFOGA"). The principal piece of this study focuses on the estimation of the critical gaps while the second part draws our attention towards various models relating variables like accepted gaps and critical gaps with other traffic characteristics like through/conflicting traffic flow and speed, driver's waiting time for different modes of transport for all the sections selected for this study. A statistical analysis software named as Statistical Package for Social Sciences (IBM-SPSS 22.0) was used to perform paired sample t-test and One-way ANOVA tests for the critical gap values between the methods used to find significance in comparison. Some of the soft wares used for curve fitting, data organization and statistical analysis of critical gaps include Origin Lab 9.1, Graph Pad Prism 6.0 and MS-Excel 2013. Radar plots, cluster diagrams, box-plots, t-statistic and two-tailed significance values coupled with higher ranges of critical gap values for different modes(except Sport Utility Vehicles) validates the fact that "INAFOGA" method is indeed appropriate to address U-turn gap acceptance behaviour under Indian mixed traffic conditions. Other methods found appropriate near to "INAFOGA" are Ning Wu's Macroscopic Probability Equilibrium, Maximum likelihood and Harders methods. ANOVA regression modelling is done in IBM –SPSS which resulted in predicting power variation of merging time with accepted gaps for both male and female 2 Wheeler drivers.

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List of Abbreviations, Nomenclature and Symbols

$\boldsymbol{T_c}$ denotes Critical gaps (seconds)

$\boldsymbol{\Delta t}$ denotes the time increment for Gap Analysis

$\boldsymbol{t_1}$ is the initial time instant for Modified Raff Method

$\boldsymbol{t_2}$ is the final time instant for Modified Raff Method

$\boldsymbol{r}$ denotes the number of rejected gaps

$\boldsymbol{n}$ denotes the no. of total gaps

$\boldsymbol{p}$ denotes the intercept for proportion of accepted gaps

$\boldsymbol{m}$ denotes the intercept for proportion of rejected gaps

$\boldsymbol{\mu_a}$ represents the mean of accepted gaps

$\boldsymbol{p}$ is the major street traffic volume in vps

$\boldsymbol{\sigma_a^2}$ is the variance of the accepted gaps

$\boldsymbol{\sigma_c}$ represents the standard deviation of the critical gaps

$\boldsymbol{t_f}$ denotes follow-up-time in seconds for continuous queuing at median opening

$\mathbf{N}_i$ denotes the number of all gaps of size *i*, that are provide to U-turn vehicles in Harders Method

$\mathbf{A}_i$ denotes the total no. of accepted gaps in Harders Method

$\mathbf{a}_i$ denotes the proportion of accepted gaps in Harders Method

$\mathbf{F_r(t)}$ represents the probability frequency distribution of rejected gaps

$\mathbf{F_a(t)}$ denotes the probability frequency distribution of accepted gaps

$\mathbf{F_c(t)}$ denotes the probability frequency distribution of critical gaps

$\boldsymbol{L}^*$ denotes the likelihood function of n no. of drivers for critical gaps

$\boldsymbol{F(yi)}$ denotes the cumulative normal distribution of logarithm of accepted gaps by i^{th} driver

$\boldsymbol{F(xi)}$ denotes the cumulative normal distribution of logarithm of rejected gaps by i^{th} driver

μ = mean of the distribution of the logarithm of individual drivers critical gap

$\boldsymbol{\sigma^2}$ = variance of the distribution of the logarithm of individual drivers critical gap

$\boldsymbol{E(t_c)}$ denotes the mean expectation of the critical gaps of size i

$\boldsymbol{D(t_c)}$ denotes the variance of the critical gaps of size i

$\boldsymbol{T_0}$ time instant front bumper of through traffic vehicle preceding the subject vehicle touches the U/S end of INAFOGA

$\boldsymbol{T_1}$ time instant front bumper of the subject vehicle touches the stop line in b/w the median opening

$\boldsymbol{T_2}$ time instant front bumper of the first through traffic vehicle after arrival of the subject vehicle touches the U/S end of "INAFOGA"

$\boldsymbol{T_w}$ time instant at which back bumper of the subject vehicle touches the stop line

$\boldsymbol{T_m}$ time instant back bumper of the subject vehicle touches the D/S end of "INAFOGA"

N denotes the total no. of sample sizes in the a statistical test

D.f represents the total no. of degrees of freedom = N-1

Sig. represents the two-tailed significance for a t-test

C.I. denotes the confidence intervals in a t-test or ANOVA analysis

p in a t-test or ANOVA table represents the two-tailed significance value

SEM denotes Standard mean error

$\boldsymbol{H_0}$ denotes the null hypothesis in hypothesis testing

$\boldsymbol{H_1}$ represents the alternative hypothesis in hypothesis testing

R-square denotes the regression squared value in regression analysis

“INAFOGA” can be named as Influence Line for Gap Acceptance

ANOVA can be named as Analysis Of Variance

$\mathbf{T_w}$ denotes the U-turn driver waiting time in seconds

$\mathbf{V_{th}}$ may be named as the conflicting/oncoming/through traffic speed in kmph

$\mathbf{Q_{th}}$ may be named as the conflicting/oncoming/through traffic flow in PCU/secs

PCU named as Passenger Car Units

IRC named as Indian Roads Congress

HCM named as Highway Capacity Manual

NCHRP named as National Co-operative Highway Research Program

CHAPTER 1

INTRODUCTION

1.1 Background

As a piece of traffic administration framework so as to enhance intersection operation, some illegal traffic movements are not permitted at selected intersection locations, especially along divided arterials. In most cases, such minor movements are accommodated at separate U-turn median openings. Throughout the late period there has been expanded establishment of un-signalized median openings to accommodate these illegal U-turns in most of the Indian states. This expanded establishment reflects the quite required consideration towards Access Management. One of the most ideal methods for assessing roads is by introducing by installing non-traversable and un-signalized median openings (Boddapati, 2001 & Hu, 2007). The motivation behind utilizing non-traversable and directional median openings is to kill issues connected with left-turns and crossing movements at intersections on multi-lane highways (Liu, 2006, 2007, 2008). At un-signalized median openings vehicular interactions are greatly mind boggling (Al-Taei, 2010 & Turki, 2013). Thus, a U-turning vehicle driver needs to accept a gap or time span between the arrivals of successive vehicles on the through street after it has arrived at a close vicinity of the median opening. This characterizes the wonder of “Gap Acceptance” for median openings. Conventionally, Gap is defined as the time or space headway between two successive vehicles in the through traffic stream (Solberg, 1964 & Uber, 1994). Gap differs from headway in the fact that the latter is measured as time span between front bumpers of two successive vehicles while the former as the time length between back bumpers/wheel bases. “Gap acceptance” analysis forms the prime objective for safe operation of U-turning vehicles at Median Openings under heterogeneous traffic situations.

Critical gap is an important parameter in “gap acceptance” study. The definition of critical gap has experienced certain changes over the previous decades (Chandra et al., 2011). Raff and Hart (1950) defined critical gap as the size of the gap whose number of accepted gaps shorter than it is equal to the number of rejected gaps longer than it (Hewitt,1983). “Highway Capacity Manual (2010)” in its Volume 3, Page 19-7 names critical gaps as “Critical Headway” and defines “as the minimum time interval in the major street traffic stream that allows intersection entry for one minor-street vehicle” (HCM,2010). Concerning above definition we attempted to define “Critical Gap” for U-turns at median openings as “the minimum time interval in between two through/conflicting traffic vehicles that allows complete merging movement for one U-turn vehicle at a median opening”. Gaps that are smaller than the critical gap usually are rejected, and all gaps larger than this critical gap are expected to be accepted. Critical gap is troublesome to measure specifically in field. It is assumed to be a constant or follow a particular probability distribution depending on the driver psychology. The estimation shifts for diverse drivers and with respect to time depending upon the geometry of the U-turn manoeuvres on median openings (Hewitt, 1983 & Toledo et al., 2011). There are a group of valuable estimation strategies for critical gaps corresponding to homogeneous traffic conditions. Some of these estimation procedures are observational although rest have a solid hypothetical foundation (Brilon et al., 1999). In this paper, two of the previous estimation techniques viz. “INAFOGA” and “Macroscopic Probability Equilibrium” methods has been used to estimate critical gaps for various modes of U-turning vehicles willing to merge with the through traffic stream at un-signalized median openings.

In heterogeneous conditions a lot of conflicting movements and illegal lane changing operations result in accidents and congestion at the median opening sections. Gap acceptance analysis in lieu of median openings under varying road geometrics coupled with heterogeneous conditions has not been given proper consideration. The traffic engineering manual HCM, even in its recent issue of 2010 had not addressed the gap acceptance study for median openings.

In this study, an intrepid effort has been taken to estimate and compare critical gaps of different U-turning modes prevailing on the median openings in India which would further prompt to understand the gap acceptance concept under mixed traffic environments. In this repute, video data has been collected from three cities located in the eastern part of India. Gap acceptance under mixed traffic is extremely difficult to evaluate and corroborate. Thus, the merging concept of critical gap analysis has been developed from the "INAFOGA" method to obtain gap related variables. All the variables obtained were used to estimate critical gaps by utilising the two methods discussed in this paper. It has been observed from the results that "INAFOGA" method is indeed more appropriate than Probability Equilibrium method in addressing the mixed traffic situations in India.

1.1.1 Gap Acceptance at Median Openings

At un-signalized median openings vehicular interactions are extremely complex. Drivers intending to take a U-turn in order to blend into an arterial are presented with a series of gaps between vehicles in the through traffic stream, which it causes to merge. A U-turning driver needs to get hold of any of these gaps in order to merge with the through traffic stream and this decision is influenced by certain behavioural considerations. This phenomenon is called as “Gap Acceptance”. Gap is defined as the time or space headway between two successive vehicles in the through traffic stream. There are some obvious contradictions regarding the definition of “GAP”. Ashworth and Green (1966) measured “gap” from rear end of one vehicle to the front of the following vehicle. Polus (1983) defined “gap” as the time interval between two successive vehicles in the through traffic stream. At Median Openings, drivers usually need larger gaps in order to merge with the through traffic stream as compared to other intersection manoeuvres. Along with “gap” comes another term “Lag”. With reference to the definition of “Lag” given by Solberg and Oppenlander (1996) , the same can be defined for “median openings” as the time interval between the arrival of a U-Turning vehicle on the median opening at the stop line and the arrival of the next (first) vehicle of the through traffic stream perpendicular to this line. Actually “lag” is the remaining part of “gap” offered to the driver on his arrival at the stop line. “Gap acceptance” is the process through which a driver has to evaluate the gaps and evaluate whether they are enough or not for merging. Referring to the Global manual in Traffic Engineering named “Highway Capacity Manual” (2010), “gap acceptance” theory includes three basic elements: the size and distribution (availability) of gaps to the drivers, their usefulness to the drivers along with the priority considerations. “Gap acceptance” has been applied widely in the estimation of Capacity, Delay and Level of Service at various transportation facilities.

1.1.2 Importance of “Critical Gap” in traffic flow

CRITICAL GAP is an important parameter in “gap acceptance” study. The definition of critical gap has undergone rigorous modifications over the past decades. The earliest definition was given by Greenshield who referred it as “acceptable average minimum time gap” and defined as the gap accepted by 50% of drivers willing to merge/cross. The definition of critical gap has undergone certain modifications over the past decades. Raff and Hart (1950) defined critical gap as the size of the gap whose number of accepted gaps shorter than it is equal to the number of rejected gaps longer than it. “Highway Capacity Manual (2010)” in its Volume 3, Page 19-7 names critical gaps as “Critical Headway” and defines “as the minimum time interval in the major street traffic stream that allows intersection entry for one minor-street vehicle”. Regarding the above definition we tried to define “Critical Gap” for U-turns at median openings as “the minimum time interval in between two through/conflicting traffic vehicles that allows complete merging manoeuvre for one U-turn vehicle at a median opening”. Critical gap is difficult to measure directly in field. The measurement varies for different drivers and with time instants depending upon manoeuvres of the U-turn vehicles under mixed traffic conditions prevailing on the median openings. There are a bunch of useful estimation procedures for determination of critical gap corresponding to homogeneous traffic conditions. Some of the estimation procedures are empirical whereas rest have a strong theoretical background. In this study some of the previous estimation techniques are used to estimate critical gaps for various modes of U-turning vehicles willing to merge with the through traffic stream at un-signalized median openings.

1.2 Problem Statements and Motivation of the Work

1.2.1 Problems due to Mixed Traffic situations at Median Openings in INDIA:

The traffic in India is exceedingly heterogeneous comprising of an assortment of quick moving vehicles such as car, bus, truck, scooter(motorized two-wheeler), auto rickshaw (motorized three-wheeler)and slow moving vehicle such as bicycle and pedal rickshaw. The static and dynamic aspects of these vehicles change altogether. In the absence of lane discipline and wide variation in sizes of different types of vehicles, vehicles willing to take U-turns are found to queue back to back near the median openings. Smaller size vehicles often squeeze through any available gap between large size vehicles and move into the median opening area in haphazard manner. The rule of priority is frequently disregarded and the U-turn stream vehicles enter the median opening area even in smaller gaps forcing the through/conflicting traffic stream to slow down and provide sufficient gaps for their movement. It changes the behavior of through traffic vehicles altogether and the gaps offered to the U-turn vehicles are not the natural time headway, but the modified ones. This forced gap acceptance which happens because of non- adherence to necessity, significantly affects the entry capacity of the lower priority stream and causes substantial delay to higher priority movements. It makes gap acceptance an extremely unpredictable phenomenon. All these situations require a re-look into the concept of critical gap, conflict area at the median opening and method of data extraction.

1.2.2 Motivation of Work

The problems faced by U-turn drivers at the selected median opening sites motivated the researchers to develop a concept of merging behaviour of U-turn drivers at median openings which would in a broad extent help future traffic engineers in analysing the accident rates and take measures to combat them with possible solutions. As because "critical gap" is the sole parameter for analysing gap acceptance for U-turns, which cannot be directly measured standing at the site or the field in consideration. The mixed traffic conditions and the inclusion of non-motorized modes inside the road networks drove the researchers to compare critical gaps between different motorized modes for each sections of video data collected from the median openings. The variation in gender for two-wheeler drivers leads to reduction or increase of accepted gaps and merging times for U-turn flow. Existing methodologies like Raff, Harders, Ashworth and Maximum likelihood methods has been used under homogeneous traffic conditions. This study focusses on utilising the above methods under heterogeneity of Indian traffic. There is an urgent need for comparison of the above methods with the "INAFOGA" method for U-turning mixed traffic in India. Thus, comparisons and significance tests are shown to validate the above statement. Other important traffic characteristics such as conflicting and U-turn traffic flow and speed, driver's waiting time at openings, follow-up-time for continuous queuing near openings and delay during U-turn merging movement affect U-turn gap acceptance and critical gaps in a great extent. Thus, empirical models have been prepared in this research between critical gap and other traffic parameters to account for U-turn gap acceptance.

1.3 Objective and Organization of the Report

1.3.1 Research Objectives:

The study was begun with no altered destinations however it absolutely had an "AIM" which will be examined under this heading. Based on the above mentioned problems, following are the tentative research objectives:

- Estimation and comparison of critical gap through existing methodologies and models present at a median opening for U-turns under mixed traffic
- Comparison of critical gap values b/w different motorized modes of transport prevalent under mixed traffic conditions at median openings
- To find the relationships between accepted gaps and merging times for U-turn 2 wheeler drivers based on Gender
- Modelling critical gap along with conflicting/ through traffic flow and speed under mixed traffic
- To study the effect of driver waiting time on critical gaps of U-turn vehicles

- The aim of the research is to estimate capacity of U-turns at median openings under mixed traffic

1.3.2 Organization of the Report:

The main part/first chapter gives a prologue to this research and likewise portrays the objective and extent of this study. In addition to the later the first chapter clearly represents the issues prompting the advancement of this research. The second chapter gives idea about the mother keywords related to the topic like U-turns, Median openings, Critical gap and the concepts of mixed traffic prevailing in INDIA. Third chapter deals with discussion on various literatures related to the Critical gap, median openings and theory behind existing methods in determining critical gap under homogeneous traffic conditions and how to tackle with the non-homogeneity of traffic while estimating critical gap for U-turn median openings. The fourth chapter gives a brief idea about the various methods and model used by the author and the ways of estimating "Critical Gaps" for U-turns taking place on median openings. The fifth chapter attracts our thoughtfulness regarding the study range for leading the research and subtle elements of the data collected in the wake of picking a suitable study area. Sixth chapter provides information about the result and possible analysis procedures conducted. The last chapter gives the summary of this study and conclusions of the work. Limitations in the current study and scope for future work are illustrated. References and Appendix are provided at the end of the report.

CHAPTER 2

U-TURN MEDIAN OPENINGS, GAP ACCEPTANCE AND MIXED TRAFFIC CONCEPTS

2.1 Introduction

This chapter comprises a detailed foresight of three major components of this report. The term “Median” expresses us the area which separates opposing lanes of traffic primarily installed or constructed on divided roads like divided highways. Progressively, U-turns at median are utilized as an option to guide left turns to decrease clashes and enhance movement operation along arterial roads when the volumes on directions are high. Contrasted and other turning developments at convergences (right/left turn), U-turn development at median openings is exceedingly intricate and dangerous. Typically, the velocity of conflicting traffic stream (main street volume) is to some degree high and the U-turn vehicles must hold up and afterward turn with incredible alert in light of the fact that this move is moderately troublesome. Critical gap is an important parameter in gap acceptance behavior of U-turning drivers willing to merge with the through traffic. Estimation of critical gap under blended traffic situation is more unpredictable than that under homogeneous movement conditions. The diverse sorts of vehicles found in India and developing nations have broadly shifting operational aspects, for example, speed, mobility, powerful measurements, and power to weight ratio and reaction to the vicinity of different vehicles in the movement stream. All these vehicles impart the same roadway without any physical isolation. Gap acceptance process gets unpredictable because of absence of path control, complex queue arrangement, and non-adherence to rule of priority of movements, absence of proper lane marking, and generous velocity variety among the vehicles sorts.

2.2 U-turn Median Openings

The median serves as a storage space for the left turning and the through movement traffic from the minor road. U-turns at median openings are utilized as an option to administer left turns keeping in mind the end goal to lessen clashes and enhance movement operation along divided arterial streets when the volumes on both directions are high. U-turn at median openings has been broadly utilized as a part of the outline of a divided arterial road. Left turn departure onto the main street is disallowed in a few outlines of the arterial roads. As an option, U-turn bays at medians ahead of time of intersections is provided to oblige these developments. Continuously, traffic engineering specialists and organizers give careful consideration to this treatment in light of the fact that such a configuration, if utilized legitimately, can enhance safety and movement operation.

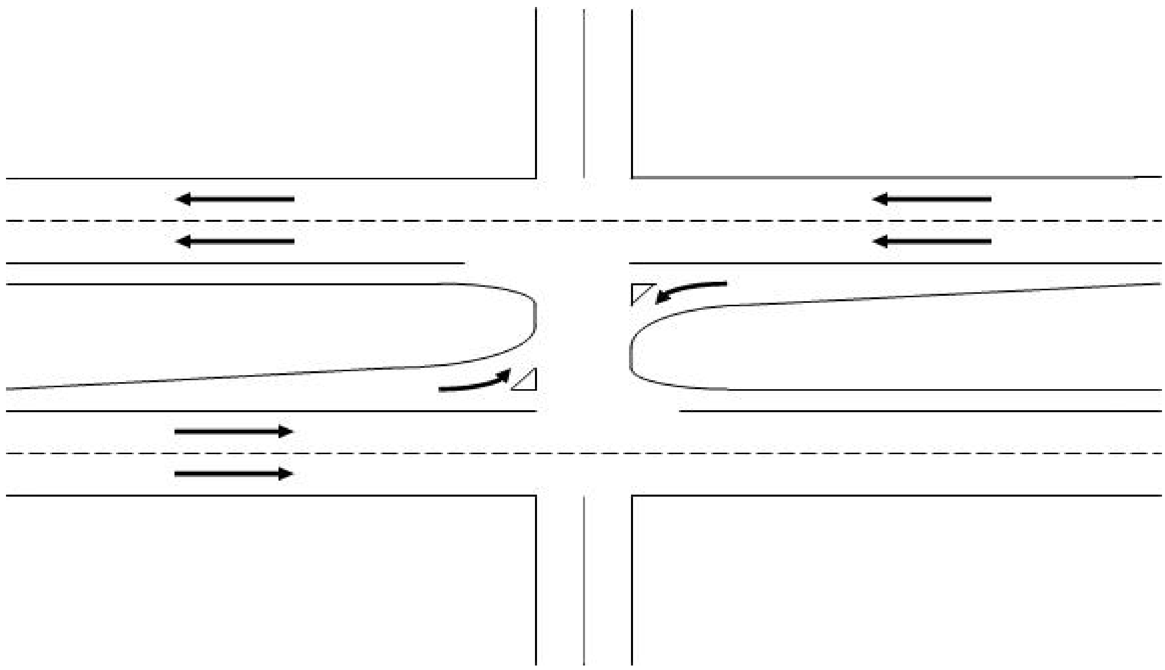


Fig. 2.1: Typical layout of a median opening on 4-lane Road

Then again, gap acceptance study at U-turn median openings has not yet been tended to in the Highway Capacity Manual (HCM 2000). Many studies have been made on gap acceptances of right turn and left turn for any conditions, however there are not many studies on U-turn gap acceptances. From literature survey, it was observed that there was one and only paper handling the qualities of U-turn gap acceptance situation under heterogeneous traffic situation. By and large, the U-turn operation could be considered as a communication of drivers on the minor or stop-controlled turn with drivers on the oncoming approach of the main street. Like the meaning of right/left turn gaps, U-turn gap is the time progress between two vehicles on the major road into which a U-turn vehicle may decide to run. In spite of the fact that the U-turn development appears to be more unpredictable than right or left turning developments at un-signalized convergences, the general ideas and methods produced for examining gap acceptances are fundamentally the same. Traffic operations at U-turn median openings have not yet been formally addressed until today. A study by Hashem R. Al-Masaeid created regression equations to gauge the delay and capacity of U-turns by field test.

2.3 Gap Acceptance and Critical Gap

2.3.1 The concept of Gap acceptance

Gap acceptance models have been generally utilized for capacities of minor developments at un-signalized intersections. Critical gap and follow-up time are two key parameters in a gap acceptance model. The critical gap t_c could be characterized as the base time interim between the major stream vehicles that is essential for one minor stream vehicle to make a move. Values of critical gaps are different for different drivers (some of them are too fast or risky, some of them are slow or careful) and there are dependent on types of movements, geometry parameters of intersections, traffic situation. Due to this variability gap acceptance process is consider as a stochastic process and the critical gaps are random variables. The estimation of critical gaps tries to figure out values for the variables and additionally for the parameters of their dispersions, which speak to regular driver behavior at the researched transportation facility.

2.3.2 "Critical Gap" – an important parameter

Critical gap is an essential parameter in gap acceptance conduct. It is the critical gap that is satisfactory to a driver, aiming to cross a conflicting/through stream. For a steady driver its esteem lies between the biggest rejected gap and the one finally accepted. Critical gap can't be specifically measured in field. It's worth contrasts from driver to driver, occasionally, between intersections, kind of development and movement circumstances. All these elements make estimation of critical gaps a troublesome process and have prompted the improvement of distinctive models/methods, each one having its playing point and detriment and making their suppositions. A portion of the models are empirical in nature while some have solid hypothetical foundation. Information regarding critical gaps is paramount as to estimation of capacity of an individual movement or of the transportation facility as a whole. The meaning of critical gaps has experienced noteworthy alterations throughout the years. One of the most punctual definitions was given by Greenshield who characterized it as the gap range that has equivalent number of acceptances and rejections. Raff and Hart (1950) characterized critical gaps as the measure of the gaps whose number of accepted gaps shorter than it is equivalent to the amount of rejected gaps longer than it.

2.4 Features Relating Mixed Traffic Conditions in India

Estimation of critical gaps under mixed traffic situation is more perplexing than that under homogeneous movement conditions. The traffic movements in India is very heterogeneous comprising of a mixture of quick moving vehicles, for example, cars, bus, truck, scooter(motorized bike), auto rickshaw (mechanized three-wheeler)and moderate moving vehicle, for example, bicycle and pedal rickshaw. The static and element qualities of these vehicles differ fundamentally. Without path discipline and wide variety in sizes of distinctive sorts of vehicles, they are found to queue side by side in the minor road approach. More diminutive size vehicles regularly press through any accessible gap between vast size vehicles and move into the crossing point zone in aimless way. A solitary gap in the main/through traffic stream might be accepted by more than one vehicle moving parallel to one another and in the wake of intersection the clashing activity these vehicles move in a single file, after one another. The rule of priority is regularly defiled and the minor stream vehicles enter the crossing point zone even in more modest time gaps compel the U-turn vehicles to back off and give sufficient gaps to these maneuvers. It was seen throughout the video image extraction procedure that very nearly 70-75% of through traffic vehicles are compelled to back off to empower the U-turn vehicles to cross/merge with the oncoming flow stream. This is not so much because of high oncoming/U-turn vehicle volume but is because of anxious and inconsiderate conduct of U-turn vehicle drivers. It changes the conduct of oncoming/through traffic vehicles inside and out and the gaps offered to the U-turn vehicles are not the natural time headway, yet the modified ones. This forced gap acceptance which happens because of non- adherence to priority, altogether influences the passage limit of the lower priority stream vehicles and causes substantial delay to higher priority movements. These situations makes gap acceptance an extremely intricate procedure. All these circumstances oblige a re-investigate the idea of critical gap, conflict area at the U-turn median openings and strategy for video data extraction.

2.5 Chapter Summary

This chapter focusses a reader's attention towards the utility of median openings at mid-block sections in between signalised intersections or rotaries in a broad sense. The type of median openings discussed about include those with exclusive left-turn lanes, with one leg on the other side of an intersection and those at mid-block sections of roads or divided arterials with multi-lanes. Median openings are utilised to divulge the left-turn egress and inconveniencing motor-bike users causing a situation of temporary congestion at un-signalized intersections. The chapter also draws our kind attention towards the behaviour and traffic characteristics of U-turn drivers who take U-turns at such type of facilities. The behaviour of U-turn manoeuvre have never been given proper attention during the past few decades. Thus, the study was initiated fixing the goal of investigating the behaviour and traffic operations of these U-turn vehicles at bi-directional median openings. In regard of this fact, the "Gap Acceptance" concept for judging vehicular interactions at median opening sections is adopted. The term "Gap Acceptance" leads to the intervention of another important parameter known as "Critical Gap". Both the foundation behind the concept of "Gap Acceptance" and "Critical Gaps" has been clearly described in this chapter. Apart from "Gap Acceptance and Critical Gap", the chapter also describes the use of such concepts at median openings under Indian mixed traffic conditions. The problems faced be day-to-day users of such traffic facilities under Indian traffic conditions are elaborately entailed in this chapter. To sum up, the chapter gives a detailed idea about the topic on which the study is based.

CHAPTER 3

REVIEW OF LITERATURES

3.1 Introduction

Large amount of research has been done on “gap acceptance” throughout the past few decades, yet lion's share of them are focused around homogeneous traffic flow conditions. Several techniques or models have been established since the year of 1947 in literatures to estimate “critical gap” as closely as possible. Thus, it is clear that literatures regarding traffic gap acceptance phenomenon is rich. This may be possibly because of the fact that “gap acceptance” became as an easy means for estimating “capacity” at a transportation facility. Majority of literatures normally consider the accepted and rejected gaps as the key parameters in determination of critical gaps. “HCM 2010” states that critical headway/gap might be assessed on the premise of perceptions of the Largest Rejected and Smallest accepted gap relating to a given transportation facility. Speaking relevantly, a number of approaches/techniques have been prepared in the recent years starting from 1992(Trout beck et. al.) up to 2013(Turki et. al.) for measuring a driver’s critical gap at un-signalized intersections.

3.1.1 Need to determine “Critical Gap” for U-turns at median openings in India

There is a massive lack in literatures till date on critical gap estimation for U-turn manoeuvres at median openings. Only a few mathematical approaches are available on driver’s gap acceptance for U-turns due to the complexity of the vehicle interaction. Thus, a lump sum amount of researches tend to produce empirical methods leading to design and operational procedures. It would be rather effective to mention that all of these researches consider homogeneous traffic flow conditions. In a developing country like

INDIA where a wide variety of vehicles prevails on roads including SUVs, LCVs, Para-transits along with conventional modes like 4 –Wheelers, 2-Wheelers & Heavy Vehicles, there is an urgent need for ACCESS MANAGEMENT of roads. One of the best ways of Accessing roads is by installing non-traversable medians and un-signalized Median Openings. “Gap acceptance” analysis and “critical gap” estimation are the prime objectives for safe operation of U-turning manoeuvres at Median Openings under heterogeneous situations. Analysis and estimation of critical gap under mixed traffic conditions for U-turn manoeuvres has not yet been performed in INDIA.

3.2 Background of the Study

3.2.1 Review of literatures related to “Median openings”

Raff (1950) first proposed the term “critical lag” as an important parameter in the determination of “gap acceptance” for a minor street driver willing to take a directional movement in an “un-signalized intersection”. He defined it as the gap/lag for which the number of accepted lags shorter than it is equal to the number of rejected lags longer than it. He proposed a graphical model in which two cumulative distribution curves related to the no. of accepted and rejected gaps intersect to yield the value of Critical Lag (T_L). In 1974, A.J. Miller corrected the Raff’s model and concluded that it gave suitable results for light-to-medium traffic but is not acceptable in Heavy Traffic conditions. He also verified that the model gives satisfactory results for “gaps” as that obtained for “lags”. This means “critical gap” can also be obtained by the method. After Miller’s correction the method came to be known as “MODIFIED RAFF METHOD”.

3.2.2 Review of literatures related to “Gap Acceptance”

Solberg and Oppenlander (1966) connected probit examination, Raff strategy and Bissel method to assess driver behaviour at stop controlled intersections. They watched a general understanding among the results. Miller (1972) created a straightforward gap acceptance model to look at nine different methods for critical gap estimation. Recreation study was utilized to create counterfeit information and correlation was focused around the central value estimated by each method. They found that Ashworth's method and Maximum likelihood probability method gave tasteful results. Another important factor considered in many literatures is driver's behavioural characteristics like driver's age and gender groups for analysis of "driver gap acceptance". Turki et. al. in their publication released on April 2013, modelled estimated length of time gap needed by the U-turn driver based on driver's Age, Gender and the elapsed time between arriving and experiencing the gap. The study related driver-related factors on critical gap acceptance whose data were obtained by analysing 4 Median U-turn openings in Irbid City, Jordan. This reveals that a part of our mind should also focus on the behavioural characteristics of a driver willing to take a U-turn. All of these researchers assumed homogeneous traffic conditions and data were collected from different un-signalized intersection types namely two-way stop controlled intersections (TWSC), T-Junctions, four-legged junctions, etc. Research interests for determining critical gap for U-turn movements at median openings under mixed traffic conditions are still found to be barren. So, very few literatures can be reviewed for this study due to the scarcity of detailed work relating the field of study.

3.2.3 Literatures regarding "Critical Gap and Critical Gap estimation"

Ashworth (1968, 1970 and 1979) estimated the average Critical Gap ($T_{c,\ avg}$) from the Mean and Standard Deviation of gaps Accepted by the driver through an empirical mathematical relation with the major street / through traffic volume in vehicles per second. He assumed exponentially distributed major stream gaps and statistical independence between consecutive gaps with Normal distribution for Critical Gaps (T_c). Later, Miller (1972) corrected the method for a special case considering that the Critical Gaps are GAMMA DISTRIBUTED.

Hewitt (1983) inferred a method which gauges the probability distribution of the critical gaps of those drivers entering a main road at a priority junction who have dismissed the initial lag offered to them, utilizing perceptions of the sizes of the gaps declined and that in the long run accepted by the driver. Later an approximate technique was proposed whereby original probability distribution of critical gap of all drivers, including the individuals who accept the initial lag, could be evaluated from the sample form for any contrast between the distributions of critical lags and gaps. Hewitt again in 1985 described his method in detail. Previously, a similar method as the Hewitt's method was proposed by Harder which became rather popular in Germany in the year of 1968. Harder's method estimated the critical gap (T_c) by the expectation of the cumulative frequency distribution curve [$F_c(t)$] of the proportion of accepted gaps of size i , provided to all minor street/ U-turning vehicles.

Maximum likelihood (ML) technique was used for the first time in the history of "gap acceptance behaviour" at un-signalized facilities for the estimation of Critical Gap by Miller and Pretty(1968). Through the reign of time, this method has been used by several researchers and has been recommended as the most efficient and consistent method along with the Hewitt method. A Probabilistic distribution has been assumed by every researcher for estimating the critical gap values for the driver's population. Troutbeck (1992) gave a more precise form of this method with a satisfactory mathematical derivation. He used Log-Normal distribution for finding the Critical gaps (T_c). He also developed a computer program for solving the mathematical relations iteratively. Brilon (1995) used Hyper-Erlang distribution. Brilon et.al. (1997) tested some models for critical gap estimation and inference that Maximum Likelihood Method along with Hewitt Method can reproduce the real critical gap of a driver population quite reliably without depending on external parameters. Tian, Vandehey, Ning Wu, Brilon and

Troutbeck (1999) implemented maximum likelihood method to measure a driver's critical gap for Two-Way-Stop-Controlled (TWSC) intersections. They found that maximum likelihood method gave satisfactory results for the TWSCs irrespective of the geometric dissimilarities. Brilon et al (1999) compared lag, Harder, Raff, Ashworth, Logit system, probit method, Hewitt, maximum likelihood technique and Siegloch methods for critical gap estimation utilizing simulation. Best technique was chosen focused around the condition that the consequence of the estimation methodology ought not to rely on upon movement volume on the major street during the time of perception. Maximum likelihood procedure and Hewitt methods gave the best results. Trourbeck's Maximum Likelihood Model (MLM) is prescribed for assessing the critical gaps in numerous standard manuals for traffic engineering (e.g. HCM 2010, HBS 2001, and so forth.).In 1999 a simple method named as "Cumulative acceptance method" was given by Thomas R. Currin in his manual named Introduction to Traffic Engineering: A Manual for Data Collection and Analysis which used only accepted gaps and not rejected gaps for its sample size in order to estimate critical gap (T_c). This method gives results similar to those of other methods and is quite simple to implement. The only drawback was that the rejected gap data is not utilized meaning a large sample size is needed for meaningful results.

Ning Wu (2006) proposed another model for evaluating critical gaps at un-signalized intersection. The new model does not require any priority suppositions and the results are correct. Utilizing the harmony of probabilities for rejected and accepted gaps, critical gaps and its distribution might be established by the method. The procedure for actualizing the new model is straightforward and robust. For practical requisitions, an actualized EXCEL-spreadsheet might be obtained from the writer. It could be completed utilizing spreadsheet programs (e.g., EXCEL, Quatro-pro and so forth.) without iterations unlike Maximum likelihood technique. Subsequently, with the new model, a valuable and guaranteeing apparatus might be set up for professionals of traffic engineering.

Xiao Kuan Yang et.al. (2001) studied to explore the critical gap of U-turn at median openings using Raff's method and Logit model. The results from both approaches were compared and presented in this study. The field data collection was conducted with the help of computer program developed for gap acceptance study. It was also found that the distance between signalized intersection and U-turn site has greatly affected the behaviour of the drivers making U-turn movement. This was the first time that gap acceptance characteristics were investigated under the multi-lane conditions. The study was conducted with an objective of determining Capacity of U-turns at median openings which has not yet been addressed in HCM 2010.

Kyte et. al. compared several different ways for the estimation of critical gaps and concluded that the maximum likelihood method and Hewitt's method gave the best results (Kyte et al., 1996). Chandra et. al. (2002) used various methods like lag method, Raff method, Ashworth method, Harder's method, and Logit and Probit method for estimation of critical gap at uncontrolled T-intersection in mixed traffic situation. They found that the critical gaps estimated using these methods show considerable variation among themselves and Maximum likelihood Method yield satisfactory results.

3.3 Study Relating to Heterogeneous Traffic Situations in India

Ashalatha and Satish Chandra (2003) used some of the existing methods like HARDER, Logit, Probit, Modified Raff and Hewitt methods for estimation of critical gap at an un-signalized intersection. There was significant variation (12-38%) among the values which highlighted the incapability of the methods to address mixed traffic situations. Thus, they came up with an alternate procedure making use of clearing behaviour of vehicles in conjunction with gap acceptance data. The new method thus proposed by Chandra et. al.

was simple and easy to implement under Indian conditions. With due respect to Chandra et. al., this paper was selected as the “mother literature” for our study because of its robustness towards mixed traffic conditions prevailing in India. The “clearing behaviour” was converted to “merging behaviour” in case of U-turns at median openings in this study.

CHAPTER 4

METHODOLOGY AND TOOLS

4.1 Estimation of Critical Gaps

The critical gap t_c can be defined as the minimum time interval between the through traffic stream vehicles that is necessary for U-turning vehicle to make a merging maneuver. Values of critical gaps are different for different drivers (some of them are too fast or risky, some of them are slow or careful) and there are dependent on types of movements, geometry parameters of median openings, traffic situation. Due to this variability gap acceptance process is consider as a stochastic process and the critical gaps are random variables. The estimation of critical gaps tries to figure out qualities for the variables and also for the parameters of their distributions, which speak to normal driver conduct at the investigated openings. The problem is that the critical gaps cannot be measured directly. Only rejected gaps and accepted gaps of each U- turning vehicle can be measured at the Median Opening. The critical gaps can be estimated from these input data using some statistical method or procedures. For the estimation of critical gaps from the field data extracted, Seven different methods which will be used for analysis and comparison are described in this Chapter of the Report – Modified raff method (1950), Ashworth's method (1968, 1970, 1979), Harder's method (1968), Cumulative gap acceptance method (1970) Maximum likelihood method (MLM) of Troutbeck (1992) and Macroscopic probability equilibrium method of Ning Wu (2006) and "INAFOGA" method.

4.1.1 Models/Methods Utilised For Estimation of Critical Gaps

4.1.1 (A) Modified Raff Method

The method of Raff (1950) is based on macroscopic model and it is the earliest method for estimating the critical gap which is used in many countries because of its simplicity. This method involves the empirical distribution functions of accepted gaps F_a (t) and rejected gaps Fr (t). As per Raff method critical gap at un-signalized intersections is defined as "as gap/lag for which no. of accepted gaps shorter than it is equal to the no. of rejected gaps longer than it". (1950, RAFF & HART)

Arrival of mainstream vehicles can be described by a Poisson distribution but only for light- medium traffic flow condition. RAFF method involves extraction of the following inputs:

(a) Length of the gaps in secs for which the driver waits at the median opening to accept a suitable gap

(b) Accepted Gaps

(c) Rejected Gaps

Two cumulative distribution curves are drawn with no. of gaps as the ordinate & length of gaps in secs in the abscissa. One relates gap lengths t with the number of accepted gaps less than t, while the other one relates t with the number of rejected gaps greater than t. Critical Gap, T_c is obtained by projecting the intersection of these curves on the X-axis corresponding to the no. of gaps.

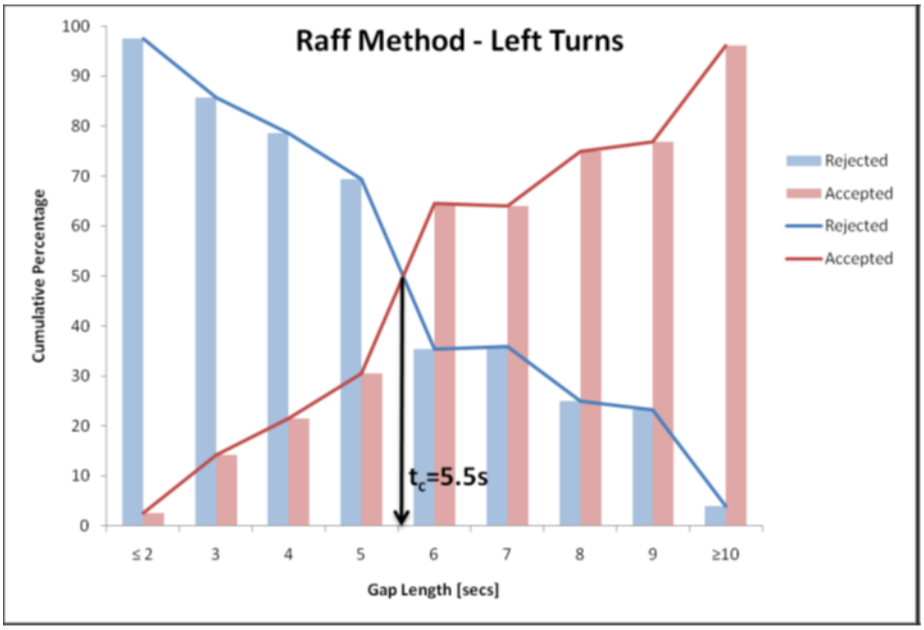


Figure 4.1 Example of Modified Raff Method for Left Turns

From the above cumulative distribution curves of accepted and rejected gaps, with an assumption of the curves being linear between two time instants t_1& t_2 , the point of intersection of these two lines represents the critical gap. Critical gap lies between t_1& $t_2 = t_1 + \Delta t$, where Δt = time increment used for Gap analysis.

Considering similar triangles, $\frac{\Delta t_1}{r-m} = \frac{\Delta t - \Delta t_1}{n-p}$ (3.1)

Now, $\Delta t_1 = \frac{\Delta t\ (r-m)}{(n-p)+(r-m)}$ (3.2)

Again critical gap, $T_c = t_1 + \Delta t_1$ (3.3)

Thus the expression of critical gap by Modified Raff method is:

$$T_c = t_1 + \frac{\Delta t\ (r-m)}{(n-p)+(r-m)} \quad (3.4)$$

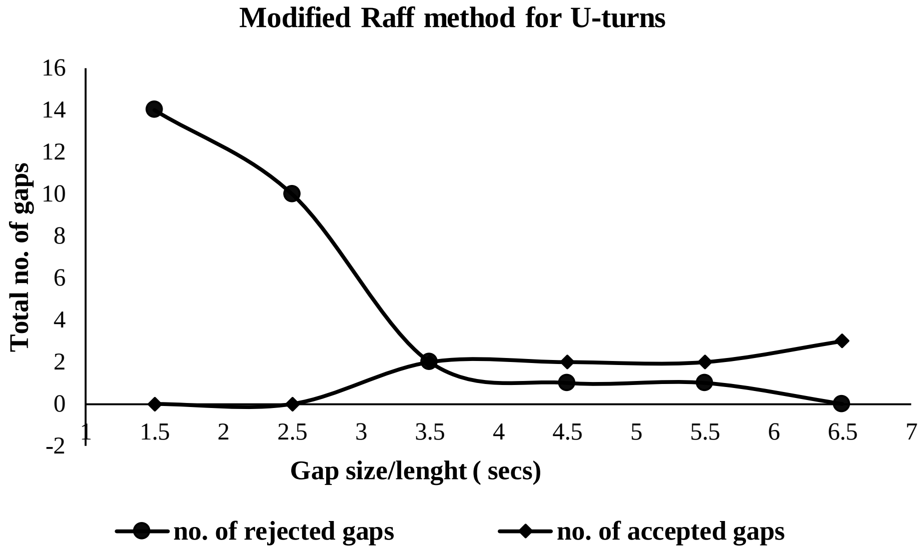


Figure 4.2 Example of Modified Raff Method for U-turns

4.1.1 (B) Ashworth's Model

Under the presumption of exponentially distributed major stream gaps with measurable freedom between consecutive gaps and ordinary dispersions for t_a and t_c. Ashworth (1968, 1970 , 1979) found that the average critical gap , t_c can be estimated from μ_a (the mean of the accepted gaps t_a, secs) and σ_a (the standard deviation of accepted gaps) by :

$$T_c = \mu_a - p.\sigma_a^2 \quad (3.5)$$

With p = major street traffic volume in vps. In the event that t_a is not normally dispersed, the result may get more muddled.

If t_c is gamma distributed or log –normally distributed the above equation gives approximate results. Miller (1972) provided an alternate correction technique for the uncommon case that the t_c are gamma distributed. At that point the two equations apply:

$$t_c = \mu_a - p.\sigma_c^2 \quad (3.6)$$

Where, $$\sigma_c = \sigma_a.\frac{t_c}{\mu_a} \text{(secs)} \quad (3.7)$$

From which t_c and σ_c are to be obtained by substitution.

4.1.1 (C) Harders Method

Harders (1968) have created a system for t_c estimation that has gotten to be somewhat famous in GERMANY. The whole practice for un- signalized intersections in Germany is still based on t_c and t_f values, which evaluated using the technique. The method only makes use of gaps. The method is similar to the Hewitt's procedure. However, for Harder's method, lags should not be used in the sample. The time scale is divided into intervals of constant duration, e.g. $\Delta t = 0.5$ secs. The centre of each time interval *i* is denoted by t_i. For every vehicle queuing on the minor road, we need to watch all major stream gaps that are displayed to the driver and, what's more, the accepted gap. From these perceptions we need to figure the accompanying frequencies and relative values:

N_i = number of all gaps of size *i*, that are provide to U-turn vehicles

A_i = number of accepted gaps of size *i*

$a_i = A_i / N_i$

Now, these a_i values can be plotted over t_i. The curve created by doing this has the type of a cumulative distribution function. It is dealt with as the capacity $F_c(t)$. Nonetheless, no one has given any convincing scientific idea that this capacity ai= capacity (ti) has genuine properties of Fc (t). Rather the methodology may be a misconception of the lag method.

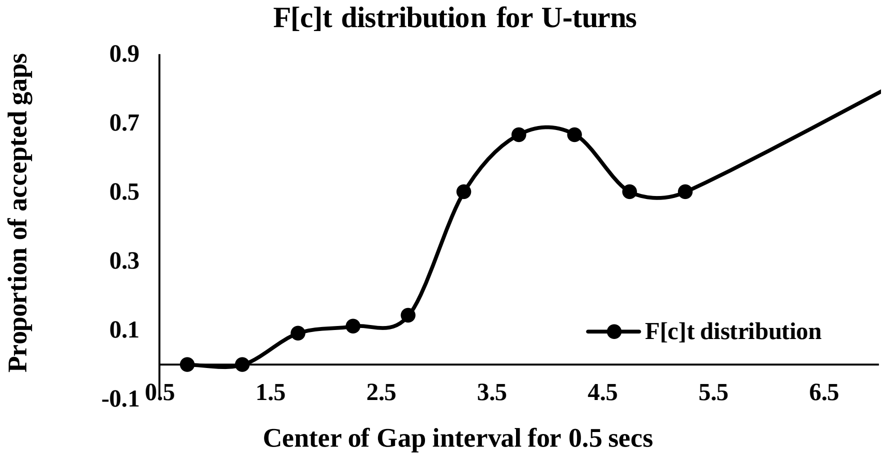


Figure 4.3 An Illustration of Harders Method

4.1.1 (D) Cumulative Gap Acceptance Method

4.1.1(D).1 Implementation

The underlying rule of this system is to distinguish a gap that would be satisfactory to 85 percent of drivers. To do this the number of accepted gaps are binned by gap length. Gap length bins of 0.25 seconds were utilized as portrayed as a part of the previously stated manual. Next, for each one gap length, the total rate of accepted gaps is arranged. As per this system, the critical gap is characterized as the gap length where the cumulative percentage is greater than or break even with to 15 percent.

4.1.1(D).2 Example size prerequisites

Since this strategy just uses accepted gaps and not rejected gaps and in addition much, a bigger information set is obliged to sensible conclusions to be drawn. The usable information from an example further decreases when gaps in excess of 12 seconds are rejected, requiring an expansive specimen size for meaningful results.

Generally, this technique gives results like those of different systems and is very easy to execute. The inconvenience of this technique is that the rejected gap information is not used importance a huge specimen size is requirement for meaningful results.

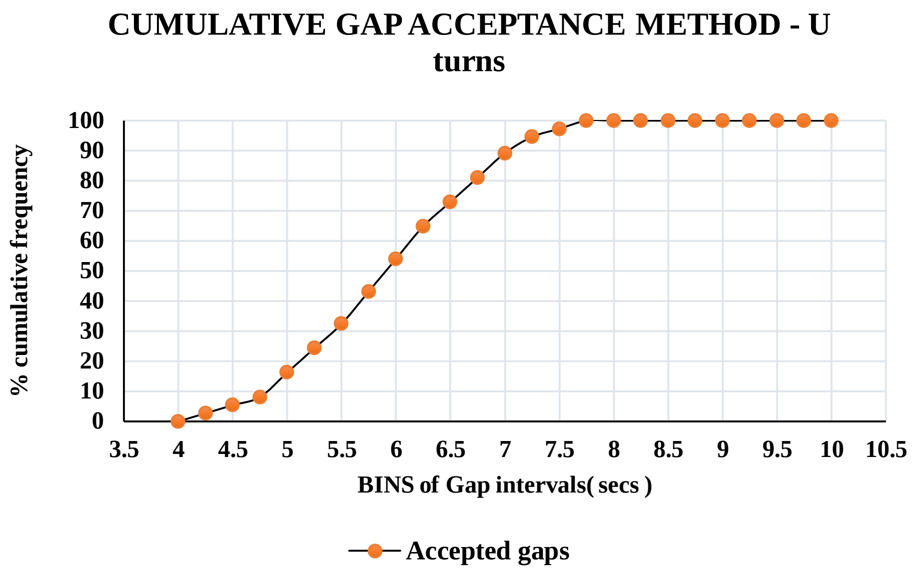


Figure 4.4. Example of Critical Gap Distribution by Cumulative Gap Acceptance Method

4.1.1 (E) Macroscopic Probability Equilibrium Method by Ning Wu

In 2006, Ning Wu presented another model for estimation of critical gaps for unsignalized crossing points. Hypothetical establishment of this model is based upon Probability Equilibrium between the Rejected & Accepted gaps. Equilibrium is secured macroscopically utilizing the cumulative distribution of rejected & accepted gaps. The new model had the accompanying positive properties: a) robust hypothetical foundation (balance of probabilities), b) hearty results, c) free of any model suppositions, d) plausibility of considering all significant gaps (not only the maximum rejected gaps as is the case of the Troutbeck model (1992)), e) possibility of attaining the observational likelihood appropriation capacity of the critical gaps straightforwardly, and f) straightforward count strategy without cycle. Critical gaps for the six sections were carried out in MS-Excel 2013 according to the following steps:

A. All measured and applicable (as per whether all or just the most extreme rejected gaps are considered) gaps in the U-turning stream noted into the first segment of the spreadsheet

B. The accepted gaps were marked with "a" and the rejected gaps with "r" in second column of the spreadsheet respectively

C. All gaps (together with their marks "a" and "r") are then sorted in a rising order

D. The aggregate frequencies of the rejected gaps were then figured, nrj, in the third column of the spreadsheet (that is: for a given row j, if mark="r" then $N_{rj}=N_{rj}+1$ else $N_{rj}=N_{rj}$, with $N_{r0}=0$)

E. Similarly, the accumulate frequencies of the accepted gaps, N_{aj}, were calculated in the fourth column of the spreadsheet (that is: for a given row j, if mark="a" then $N_{aj}=N_{aj}+1$ else $N_{aj}=N_{aj}$, with $n_{a0}=0$)

F. Then the Probability Density Function(PDF) of the rejected gaps, Fj(r), were calculated in column 5 of the spreadsheet (that is: for a given raw j, $Fj(r)=N_{rj}/N_{r,max}$ with $N_{r,max}$=number of all rejected gaps)

G. Similarly, the PDF of the accepted gaps, $F_a(tj)$, in sixth column of the spreadsheet (that is: for a given raw j, $F_a(tj)=N_{aj}/N_{a,max}$ with $N_{a,max}$=number of all accepted gaps)

H. The PDF of the estimated critical gaps, Ftc(tj) were then calculated, in column 7 of the spreadsheet as $F_{tc}(tj)=F_a(tj)/[F_a(tj)+1-F_r(tj)]$ for any j

I. Frequencies of the assessed critical gaps, $P_{tc}(tj)$, was calculated between the raw j and j-1 in column 8 of the spreadsheet as per $P_{tc}(tj)=F_{tc}(tj)-F_{tc}(tj-1)$

J. The class mean, $T_{d,j}$, between the raw j and j-1 in is the calculated in column 9 of the spreadsheet (that is: $T_{d,j}=(Tj+Tj-1)/2$)

K. Then, the average critical gap esteem and the variance of the assessed critical gaps (that is: ($T_{c,average}=sum[P_{tc}(tj)*T_{d,j}]$ and $\sigma^2=sum[Ptc(tj)*T_{d,j}^2]-(sum[Ptc(tj)*T_{d,j}])^2$) is found out

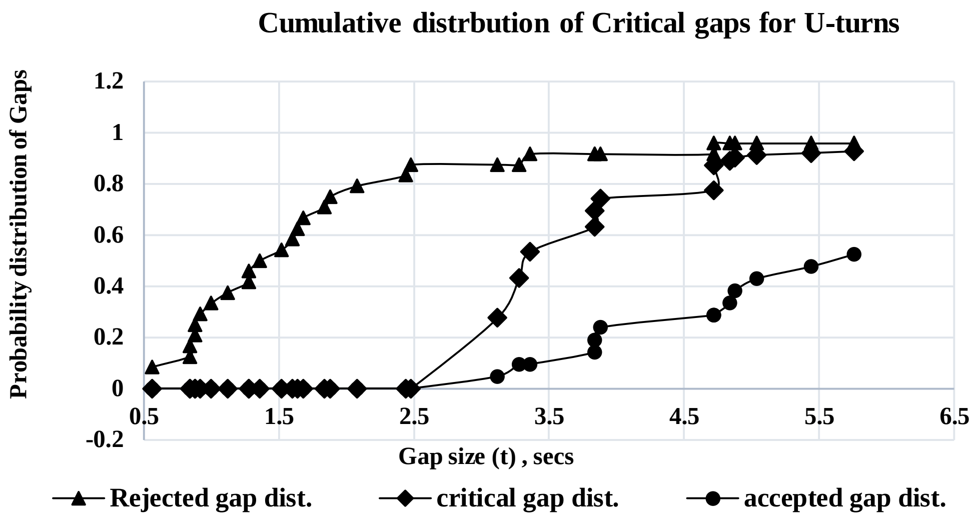


Figure 4.5 Critical Gap distribution example by Macroscopic Probability Equilibrium Method

3.1.1 (F) Influence Area for Gap Acceptance (INAFOGA) Method

Satish et al in the year of March 2011 presented another idea for measuring critical gap making utilization of clearing conduct of vehicles in conjunction with gap acceptance information. He proposed an area named as INAFOGA (Influence Area for Gap Acceptance) which had a dimension of L*W, where L= 3.5 m (lane width) & W= 1.5 times width of crossing /merging vehicle. The method considers the clearing behavior of a vehicle (clearing time is the time taken by the minor street/U-turn vehicle to clear the influence area) & gap acceptance behavior.

4.6.1 Characteristics of the "INAFOGA":

i. A vehicle taking right turn from Minor Street waits at the stop line near INAFOGA & is said to clear the crossing point when its last part crosses the stop line in the major street.
ii. Distinction between the landings of continuous major road vehicles at the upstream end of the INAFOGA is considered as 'Gap'
iii. In this method, a typical cumulative frequency distribution curve for clearing time of a minor street vehicle against its corresponding Lag & Gap Acceptance curve is plotted obligating a common point of intersection. This

point of intersection indicates the minimum/critical gap sufficient for the vehicle to enter the INAFOGA keeping in mind the Safety aspect.

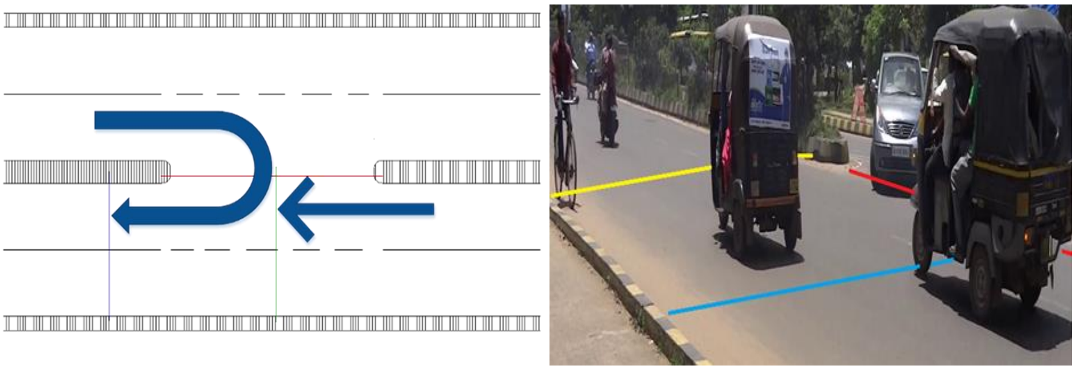


Fig. 4.6: Gap Acceptance by clearing behavior of Vehicles at U-turn Median Openings

Above figures represents the schematic diagram of a median opening on a 4-lane divided carriageway in AUTOCAD 2009 representing the “INAFOGA”method. The influence area for gap acceptance (INAFOGA) of a U-turning vehicle is the rectangular area bounded by the Red, Green and Blue lines. “Red” line represents the stop line of the U-turn vehicle after approaching the median opening while the “Yellow” and “Blue” lines form the upstream and downstream ends of “INAFOGA”. The length (L) of the area measures {(d/2) + 2.2 m} while the breadth (W) as {a + (c/2)}. All these measurements have been experimentally proved in general for all the 4 sections. The U-shaped and the straight arrows show the directions of the U-turning and through traffic respectively. Here, ‘a’ represents the distance between inner lanes while ‘b’, ‘c’ &‘d’ are dimensions of the median openings. The “Green” line is at d/2 distance horizontally from the face of the median.

Both accepted lags and gaps are used in this method to determine critical gaps. Cumulative frequency percentages of lags and gaps are plotted against merging time expressed as frequency distribution. Fig. 5 predicts the critical gap of U-turning 4 wheelers and SUVs using “INAFOGA” method.

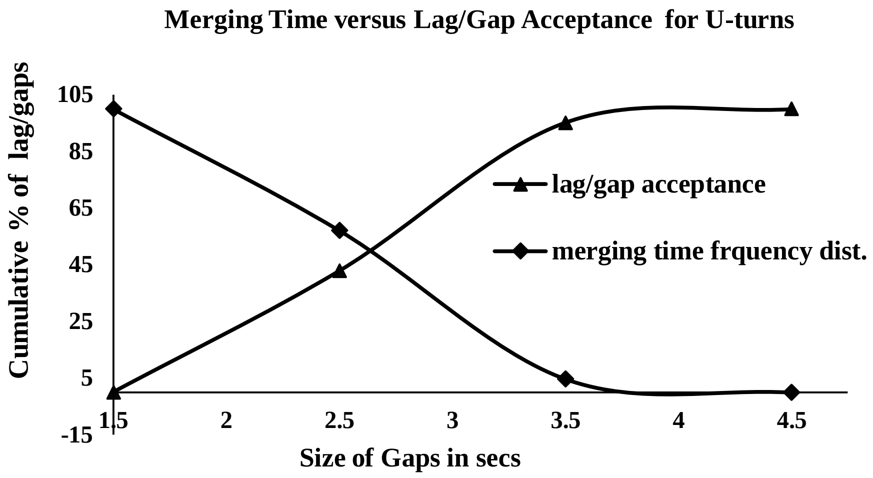


Figure 4.7 Illustration of Critical Gap estimation by "INAFOGA" Method

3.1.1 (G) Maximum Likelihood Method (MLM)

The maximum likelihood technique for evaluating critical gap is focused around the way that a driver's critical gap is between the reach of his largest rejected gap and his accepted gap. A probabilistic appropriation for the critical gaps must be expected. Troutbeck (1992) utilized a log-normal distribution for the critical gaps. The distribution is skewed to the right and has non-negative qualities, as would be normal in these circumstances. Brilon (1995) utilized the hyper-Erlang distribution. Comparable results were accounted for between the two methodologies. The foundation hypothesis is talked about beneath in which all derivations are focused around Troutbeck (1992).

The likelihood function of n no. of drivers is represented between the accepted and largest rejected gaps (y_i, x_i) as follows:

$$L^* = \prod_{i=1}^{n}[\, F(yi) - F(xi)] \qquad (3.8)$$

Where,

yi = logarithm of gaps accepted by the ith driver

xi = logarithm of largest rejected gap by ith driver (xi = 0, if no gaps rejected)

f ()= probability density function for normal distribution

F () = cumulative distribution function for normal distribution

Referring to equation no. 3.8, if we take logarithm on both sides of the equation, we get:

$$\ln L^* = \ln\{ \prod_{i-1}^{n} [\, F(yi) - F(xi)]\}$$

$$\ln L^* = \sum_{i=1}^{n} \ln[\, F(yi) - F(xi) \qquad (3.9)$$

For solving the above equation no (3.9), Trout beck assumed two estimators μ and σ^2 :

μ = mean of the distribution of the logarithm of individual drivers critical gap

σ^2 = variance of the distribution of the logarithm of individual drivers critical gap

For, maximizing the log-likelihood function, we follow the conditions:

$$\frac{\partial \ln L^*}{\partial \mu} = 0 \qquad \frac{\partial \ln L^*}{\partial \sigma^2} = 0$$

Therefore, $$\frac{\partial \ln L^*}{\partial \mu} = \sum_{i=1}^{n} \frac{\frac{\partial F(yi)}{\partial \mu} - \frac{\partial F(xi)}{\partial \mu}}{\{F(yi) - F(xi)} = 0$$

Also, $$\frac{\partial \ln L^*}{\partial \sigma^2} = \sum_{i=1}^{n} \frac{\frac{\partial F(yi)}{\partial \sigma^2} - \frac{\partial F(xi)}{\partial \sigma^2}}{\{\, F(yi) - F(xi)} = 0$$

From the properties of normal probability distribution of critical gaps:

$$\frac{\partial\, F(x)}{\partial \mu} = f(x) \qquad and \qquad \frac{\partial F(x)}{\sigma^2} = -\frac{(x-\mu)}{2\,\sigma^2}\, .f(x)$$

The governing equations of maximum likelihood method (MLM) are:

$$\frac{\partial \ln L^*}{\partial \mu} = \sum_{i=1}^{n} \frac{f(yi) - f(xi)}{\{\, F(yi) - F(xi)\}} = 0 \qquad (3.10)$$

$$\frac{\partial \ln L^*}{\partial \sigma^2} = \sum_{i=1}^{n} \frac{(\mu - yi) f(yi) - (xi - \mu) f(xi)}{\{F(yi) - F(xi)} = 0 \qquad (3.11)$$

For normal probability distribution the density function is:

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}}\, .\, e^{-\frac{(x-\mu)^2}{2\,\sigma^2}} \quad , \qquad -\infty < x < \infty$$

$$F(x) = \frac{1}{\sigma\sqrt{2\pi}}\, .\int_{-\infty}^{x} e^{-\frac{(x-\mu)^2}{2\sigma^2}}\, .dx$$

After substituting the density and distribution functions in equations 3.10 and 3.11, we get the following two equations:

$$\sum_{i=1}^{n} \frac{e^{-\frac{(yi-\mu)^2}{2.\sigma^2}} - e^{-\frac{(xi-\mu)^2}{2.\sigma^2}}}{(yi-xi)} = 0 \qquad (3.12)$$

$$\sum_{i=1}^{n} \frac{(\mu-yi)\, e^{-\frac{(yi-\mu)^2}{2.\sigma^2}} - (xi-\mu)e^{-\frac{(yi-\mu)^2}{2.\ \sigma^2}}}{(yi-xi)} = 0 \qquad (3.13)$$

From the equations 3.12 and 3.13, the values of the estimators μ and σ^2 can be obtained by numerical and iteration techniques. Subsequently, the mean E (t_c) and variance D (t_c) of critical gaps can be exemplified by the following equations:

$$E(t_c) = e^{\mu+0.5\,\sigma^2} \qquad and \qquad D(t_c) = E(t_c)^2.(e^{\sigma^2} - 1)$$

Where, t_c = denotes critical gap values in seconds

4.2 Tools/Software Used For Analysis

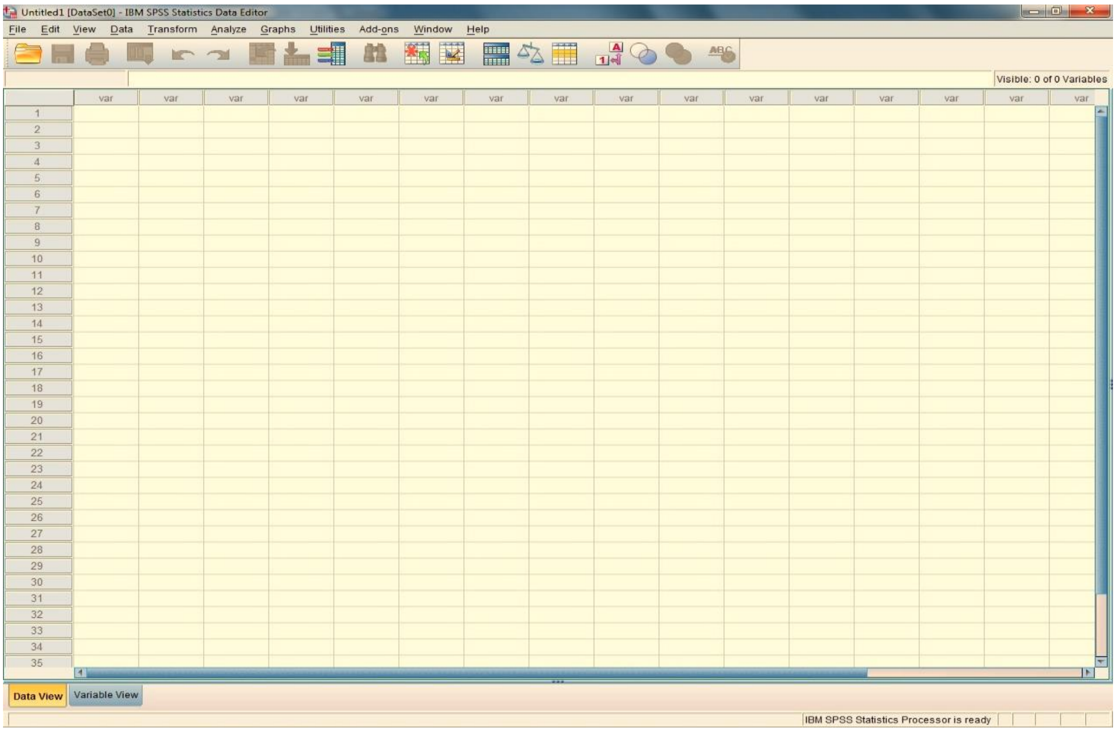
4.2.1 About IBM- Statistical Package for Social Sciences (SPSS)

SPSS Statistics is a product bundle utilized for statistical examination. As far back as anyone can remember prepared by SPSS Inc., it was gained by IBM in 2009, and current variants are formally named IBM SPSS Statistics. SPSS is among the most broadly utilized programs for statistical analysis within social science. It is additionally utilized by economic analysts, health researchers, health researchers, government, training specialists, promoting associations, and others. Statistics included in the base software:

- Descriptive statistics: Cross tabulation, Frequencies, Descriptive, Explore, Descriptive Ratio Statistics
- Bivariate statistics: Means, t-test, ANOVA, Correlation (bivariate, partial, distances), Nonparametric tests
- Prediction for numerical outcomes: Linear regression

- ➢ Prediction for identifying groups: Factor analysis, cluster analysis (two-step, K-means, hierarchical), Discriminant

The version of SPSS used for getting the descriptive statistical results is IBM SPSS Ver. 20.0.1 which had a scheduled release on March 2012. **Below is the IBM SPSS 20.0.1 Data Editor window.**



Performing the One-way ANOVA tests in SPSS indicated that critical gap comparison between "INAFOGA" and Macroscopic Probability Equilibrium and the same between Harders method is feasible under Indian mixed traffic conditions. Therefore, it is time we conduct the paired sample t-tests between the methods to ensure the significance in comparisons in SPSS.

CHAPTER-5

STUDY AREA AND DATA COLLECTION

5.1 Description of the Study Area

The study area from two cities are considered in such a fashion that the road networks give the required input data for analyzing "Critical Gap" and comparing the same between different modes of transport. Median openings at four-lane and six-lane divided urban roads are considered in the present study. In Indian context, median openings are generally provided in urban areas on major streets for minimum flow of 500 vehicles/day with maximum speed limit of 70-80 kmph.

The study area comprised of nine busy median opening sites from two cities located in the eastern part of India. Observed details on geometry and traffic characteristics of the six median openings are shown in Table 1. In order to include variation in road geometric and traffic characteristics, data were collected from two median openings corresponding to each city. Both the cities of Rourkela and Bhubaneshwar belongs to Odisha State. Heavy vehicles like busses, trucks and multi-axle vehicles are not taken into consideration because of the imposed restrictions on their maneuverability at U-turns. It is observed that, percentage of vehicles make U-turn at median openings is proportionately high as the distance of the openings from signalized/un-signalized intersections increases. Considering this fact, median openings roughly spaced at about 400-550 feet from their nearest intersections or rotaries are observed in this research. All the median openings are nearly similar in geometry with two or three lanes each on either side of the medians. The speed limit displayed on the roadsides for the conflicting or through traffic varies from 35-55 kmph for different mode of transportation. The median opening segments are all on plain landscape and in this manner sufficient sight distances were kept up for every development.

5.2 Detailed Overview of the Data Collection Process

Data collection primarily comprised of video recording of the selected median openings by a Sony Handycam capable of playing videos at a rate of 30 frames/second. Data sets were collected during peak hours for the morning (8:30- 10:30 AM), noon (12:30-2:00 PM) and afternoon (5:00-6:00 PM) between September 2013 and April 2014. Shooting was done only during weekdays. Weekends and public holidays were generally neglected due to large discrepancy among data sets which leads to erroneous estimation of critical gaps of U-turning traffic at median openings. Video recording of all the nine locations resulted in an average proportion of U –turning and through traffic of 20-40% and 65-85% respectively. Through traffic comprised of vehicles including Heavy Vehicles (HVs), Light Commercial Vehicles (LCVs), discounted non-motorized vehicles and pedestrians. Classes of U-turning vehicles considered are as pointed below:

1. Motorized 4 Wheelers (Including Sedan and Hatch Backs)
2. Motorized 2 Wheelers (Driver: Male / Female, Motor-bikes, Scooters)
3. Motorized 3 Wheelers (4-stroke-Auto-rickshaws, 3 Wheeler delivery vans)
4. Sports utility vehicles / multi utility vehicles (SUVs)

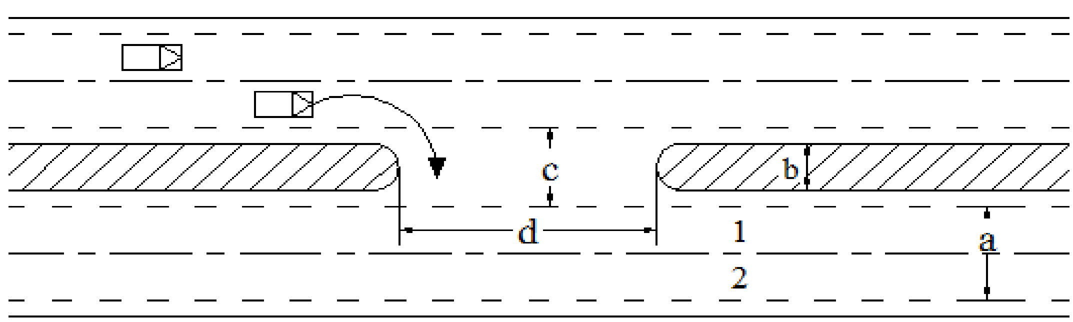


Figure 5.1 Layout of Median Opening on a 4-lane road

Table 5.1. PCUs for Flow Calculation as per Indian Roads Congress (1983), Code Number- 86

Serial Nos.	Vehicle Types	PCU Equivalents
1.	Car, LCV,3W,SUV	1.0
2.	HV like truck,bus,lorry	3.0
3.	2W(motor-bikes, scooters)	0.5

Table. 5.2. Traffic Characteristics and Geometry of the Nine Median Opening sections Observed

Median Opening Section No.	**Location**	**Median Opening Width(m)**		**Volume of through traffic (PCU/hr.)**	**Proportion of U-turn drivers**
		d*	c**		
1	Near Rourkela Institute of Management Studies – Rourkela, Odisha	14.8	2.4	4100	1184(34%)
2	Near Rainbow Software Training Complex on Panposh Road – Rourkela, Odisha	20.1	2.3	4570	715(28%)
3	In front of Pal Height Mall (Towards Jaydev Bihar) – Bhubaneshwar, Odisha	20	2.1	2490	894(20%)
4	In front of CS Pur HPCL petrol pump – Bhubaneshwar, Odisha	20.3	2.1	1980	828(25%)
5	Near Patia IOCL petrol pump – Bhubaneshwar, Odisha	20.4	2.0	6570	670(23%)
6	In front of Eastern Railway Headquarters, Bhubaneshwar	17.9	2.8	7950	1500(43%)
7	In front of SBI colony, Bhubaneshwar	15.3	2.2	2652	667(20%)
8	Near Kalinga Stadium, Bhubaneshwar	15.7	1.6	3086	1582(34%)
9	In front of Regional College of Management, Bhubaneshwar	19.8	2.2	2881	1184(29%)

d*= horizontal width of median opening; c** = distance between outer edge of inner lanes

The variation of U-turning flow with respect to through or conflicting traffic flow can graphically represented as a cumulative distribution in Passenger Car Unit (PCU)/hr. The conversion factor, PCU for different vehicle types are followed from Table 2 of Indian Roads Congress (1983), Code number -86 (Geometric Design Standards for Urban Roads on Plains). Fig. 1 shows the frequency distribution curve of U-turn flow vs through traffic flow, both expressed in PCU/hr. for six different sections. It has been observed from this figure that with increase in percentage of through traffic flow, there is an exponential decay of U-turn traffic gap acceptance.

5.2.1 Extraction of necessary decision variables as per "The Merging Behaviour" Concept

After video shooting of the median openings, extraction of necessary decision variables for the estimation of critical gap was done. The video data collected from the field was converted to .AVI format from .MPG file type. All decision variables were extracted by playing the .AVI videos in demuxer software named as AVIDEMUX Version 2.6 capable of running videos at a frame rate of 25 frames/second. The time frames chosen for data extraction were based on the new concept on merging time are explained below.

Fig. 2 represents the schematic diagram of a median opening on a 4-lane divided carriageway drawn in AUTOCAD 2009. The **IN**fluence **A**rea **FO**r **G**ap **A**cceptance (INAFOGA) of a U-turning vehicle is the rectangular area bounded by the Red, Green and Blue lines. "Red" line represents the stop line of the U-turn vehicle after approaching the median opening while the "Yellow" and "Blue" lines form the upstream and downstream ends of "INAFOGA". The length (L) of the area measures $\{(d/2) + 2.2 \text{ m}\}$ while the breadth (W) as $\{a + (c/2)\}$. All these measurements have been experimentally proved in general for all the six sections. The U-shaped and the straight arrows show the directions of the U-turning and through traffic respectively. Here, ‘a’ represents the distance between inner lanes while ‘b’, ‘c’ &‘d’ are measurements of the median openings. The “Blue” line is at d/2 distance horizontally from the face of the median.

The time frames chosen during extraction of data with the aid of AVIDEMUX software are as follows:

1. T_0 = time instant front bumper of through traffic vehicle preceding the subject vehicle touches the U/S end of INAFOGA

2. T_1 = time instant front bumper of the subject vehicle touches the stop line in b/w the median opening

3. T_2 = time instant front bumper of the first through traffic vehicle after arrival of the subject vehicle touches the U/S end of “INAFOGA”

4. T_3, T_4… T_n = corresponding time instants for arrival of through traffic vehicles on the U/S end of “INAFOGA”

5. T_w = time instant at which back bumper of the subject vehicle touches the stop line

6. T_m = time instant back bumper of the subject vehicle touches the D/S end of “INAFOGA”

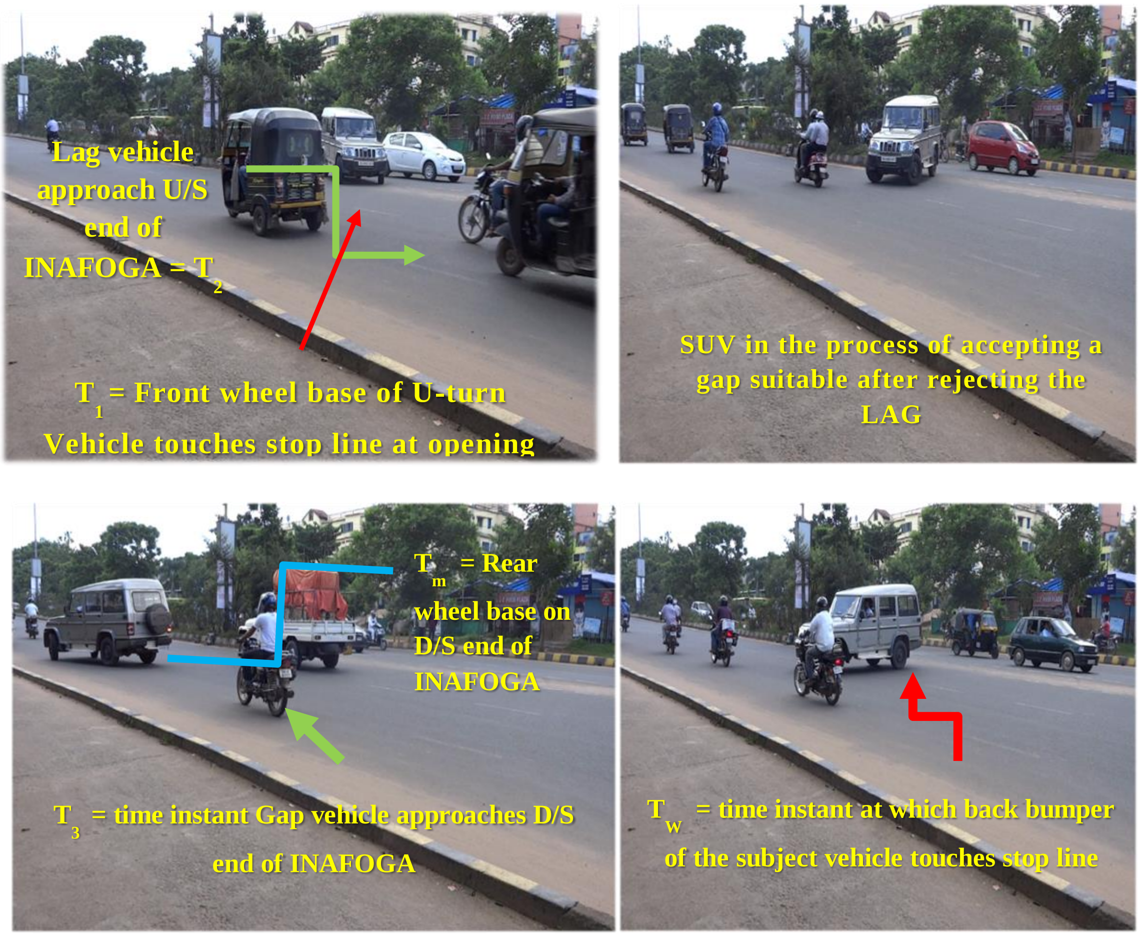
The time frames extracted from the raw video data were then represented in an Excel spreadsheet and the following decision variables or inputs were found out using the existing methods as described below:

1. LAG (only accepted) = time interval b/w arrival of U-turn vehicle on opening and arrival of first through traffic vehicle= T_2-T_1

2. GAP (accepted & rejected) = difference b/w arrivals of consecutive through traffic vehicles at U/S end of “INAFOGA” = $T_{n+1} – T_n$

3. Merging Time Of U-turning Vehicle = $T_m – T_w$

The following pictures will help understand the reader about the process of data extraction of necessary decision variables required for estimating critical gaps based on the time frames chosen above in clock-wise direction.



The Basic statistics of the decision variables like accepted gaps, rejected gaps and merging times extracted from the videos for estimation of critical gaps are represented in table 3 of this report.

Table 5.3. Basic Statistics of Data Extracted for different Motorized Modes

For 4W	**Accepted Gaps, secs**	**Rejected gaps, secs**	**All Gaps, secs**	**Merging Times**
Mean	4.55	1.94	2.64	2.46
Standard Deviation	2.835	1.64	2.505	0.744
Minimum	1.28	0.433	0.433	1.634
Maximum	14.24	15.6	15.6	4.52

For 2W	Accepted Gaps, secs	Rejected gaps, secs	All Gaps, secs	Merging Times
Mean	5.28	1.38	2.45	2.46
Standard Deviation	2.84	0.726	2.505	0.744
Minimum	0.88	0.52	0.52	0.45
Maximum	13.12	4.72	13.12	14.08

For 3W	Accepted Gaps, secs	Rejected gaps, secs	All Gaps, secs	Merging Times
Mean	5.369	1.705	2.83	2.49
Standard Deviation	1.83	1.21	2.101	0.873
Minimum	3.04	0.4	0.4	1.733
Maximum	9.567	5.833	9.567	2.5

For SUVs/MUVs	Accepted Gaps, secs	Rejected gaps, secs	All Gaps, secs	Merging times
Mean	5.97	1.79	2.65	2.77
Standard Deviation	3.39	1.09	2.265	0.92
Minimum	1	0.466	0.466	0.93
Maximum	13.44	4.384	13.44	6.6

5.3 Summary of the Chapter

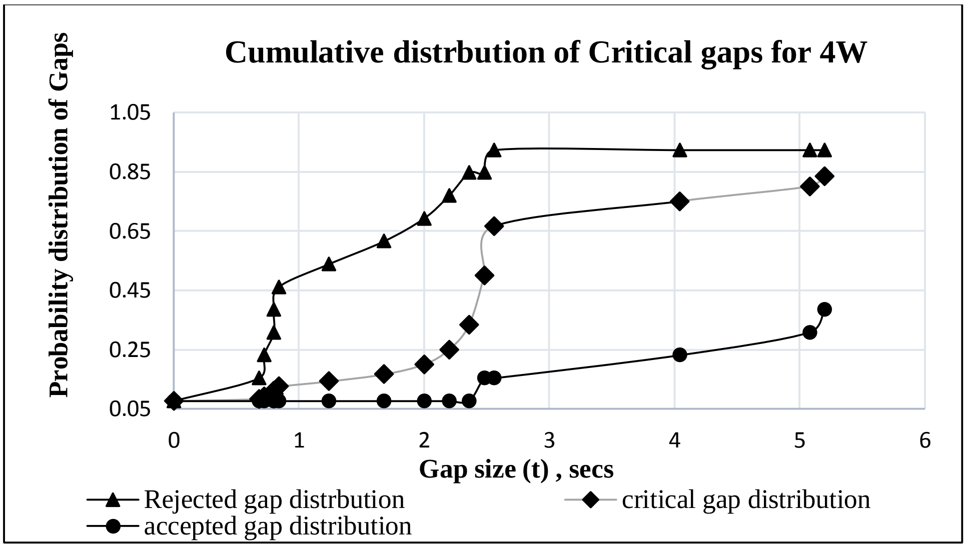
The area of study can be broadly classified based on the necessity of data for analysis of "Critical Gap" and comparison of different modes of transport. There were two types of median openings mainly prevailing in INDIA. First one being on a typical 4-lane divided highway and the second one on a 6-lane divided street. Median openings are provided in urban areas for minimum major street flow of 500 vehicles/day having a maximum speed limit of 70-80 kmph (40 miles/hr.). Bhubaneswar being the capital of Odisha consists of a large road network on which mixed traffic is dominant. Modes like four-stroke Autos, Light commercial vehicles like Tempos and Pick-up vans, Categories of cars comprising of Sedans and Hatchbacks along with other Sports utility vehicles make a wholesome of 600-500 vehicles per day on most of the U-turns prevail within the city's domain. About 13 different sections of median openings on 6-lane divided highways having 70-80 % of U-turning vehicles were selected for data collection. Correspondingly, 8 different sections of median openings on 4-lane divided highways were later studied and shot for data extraction. All the sections involved with the case study for Bhubaneswar varied in their geographical originations. Assumptions were made regarding the geometrical variations for individual sections. Each median opening were approximately spaced about 600-700 feet distance from their near unsignalized intersections as stipulated by HCM 2010. However, in some of the median openings inconsistency of drivers taking U-turns were noted but irrelative data pointe were neglected for finding "Critical Gap" values. Data were primarily collected in the form of shooting videos by Sony Handycam capable of playing videos at a frame rate of 30 frames/second. Peak hours of U-turns were surveyed and video shooting was done for the morning, noon and afternoon sessions depending on the importance of the days. Weekends were generally kept aside while collecting datas. Datas mostly involved weekdays except holidays.

CHAPTER-6

RESULTS & ANALYSIS

6.1 Estimation Procedure for Critical Gaps by Different Methods Used

6.1.1 Macroscopic Probability Equilibrium Method by Ning Wu



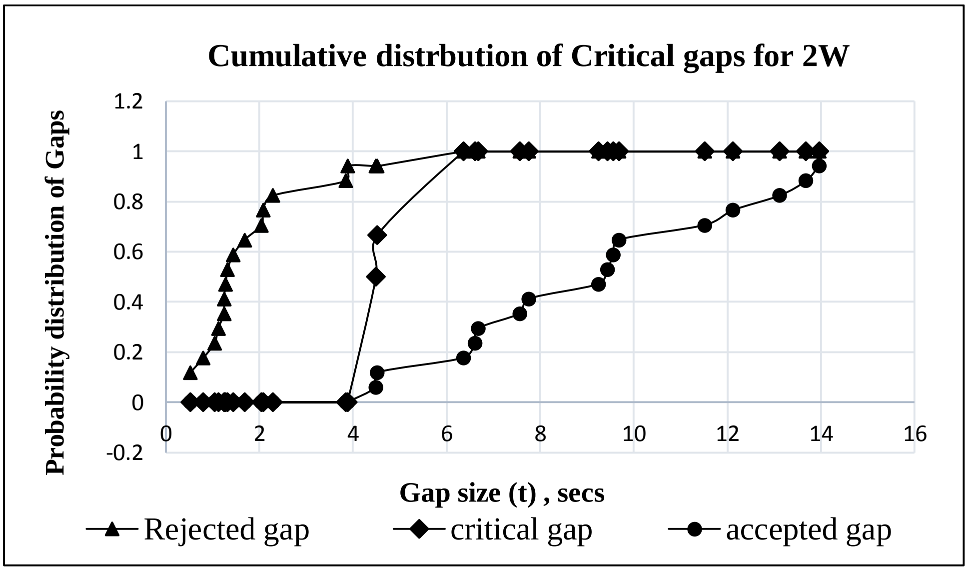
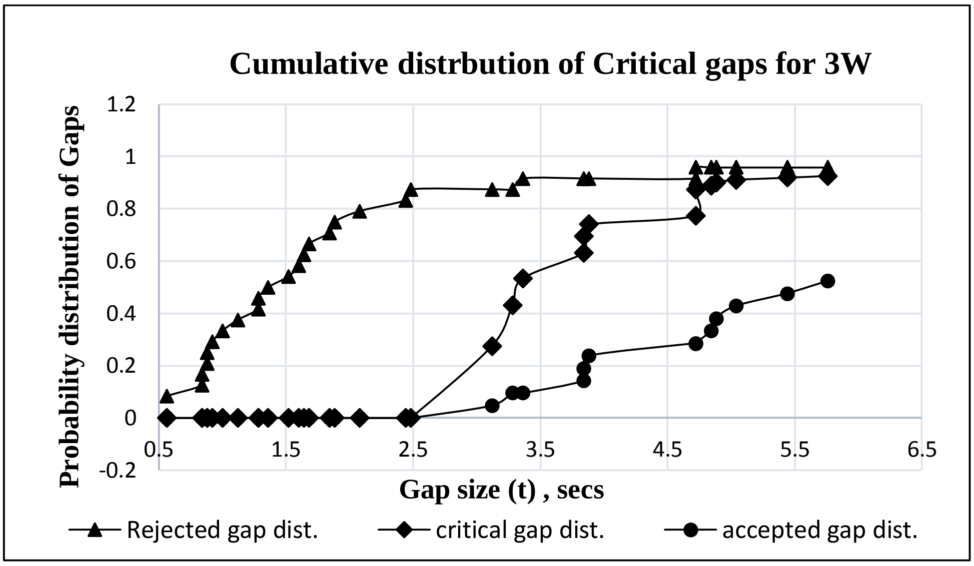


Figure 6.1 Cumulative Stochastic Distribution of Gaps by Macroscopic Probability Equilibrium Method for 4 wheelers and 2 wheelers respectively



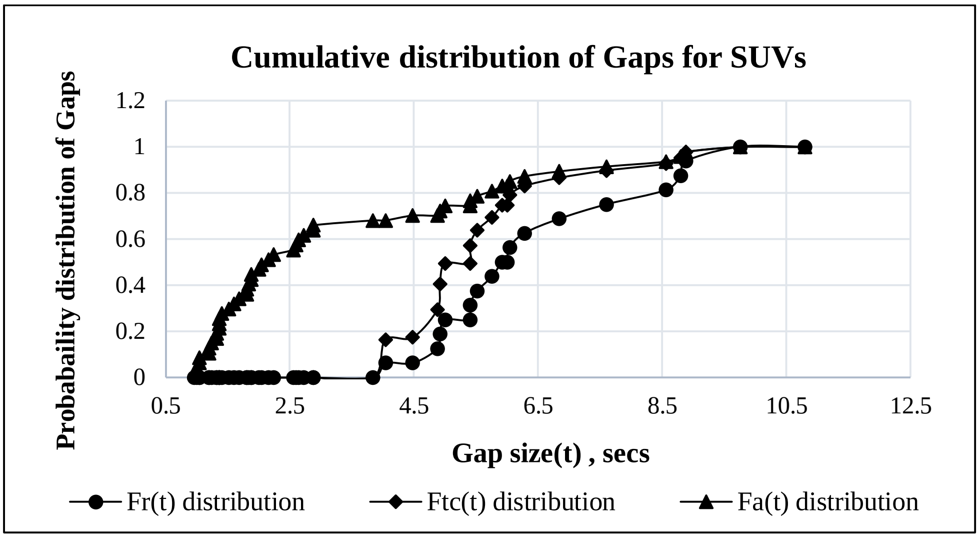
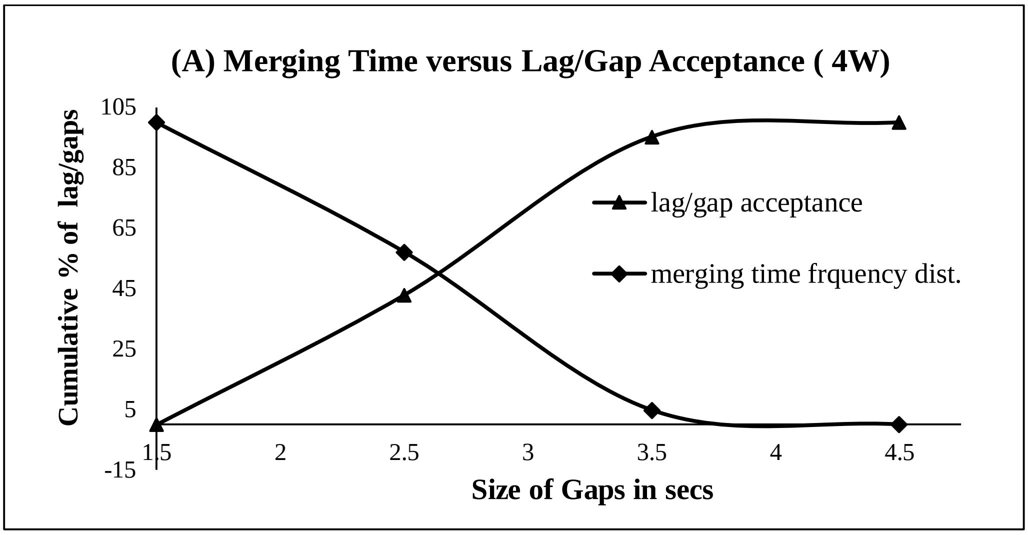
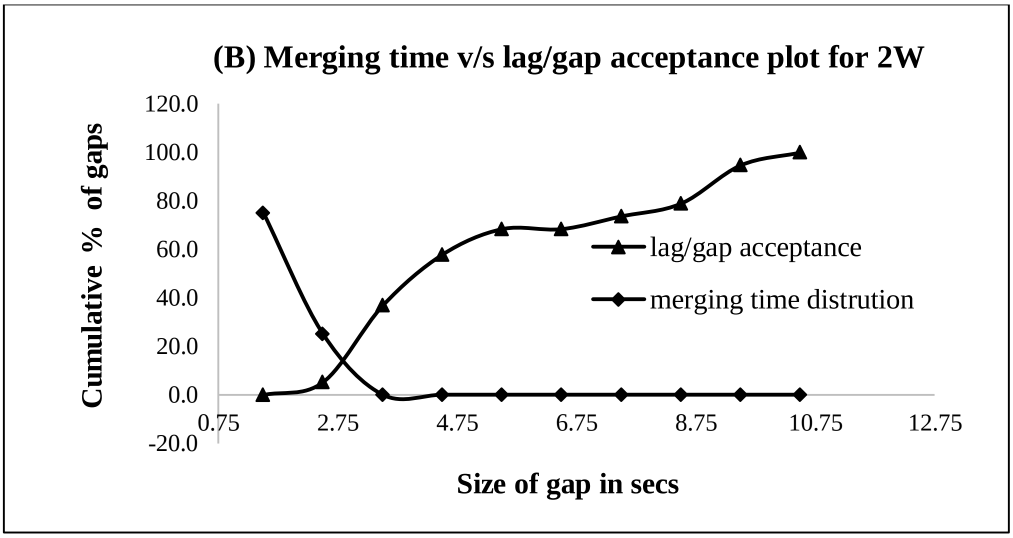


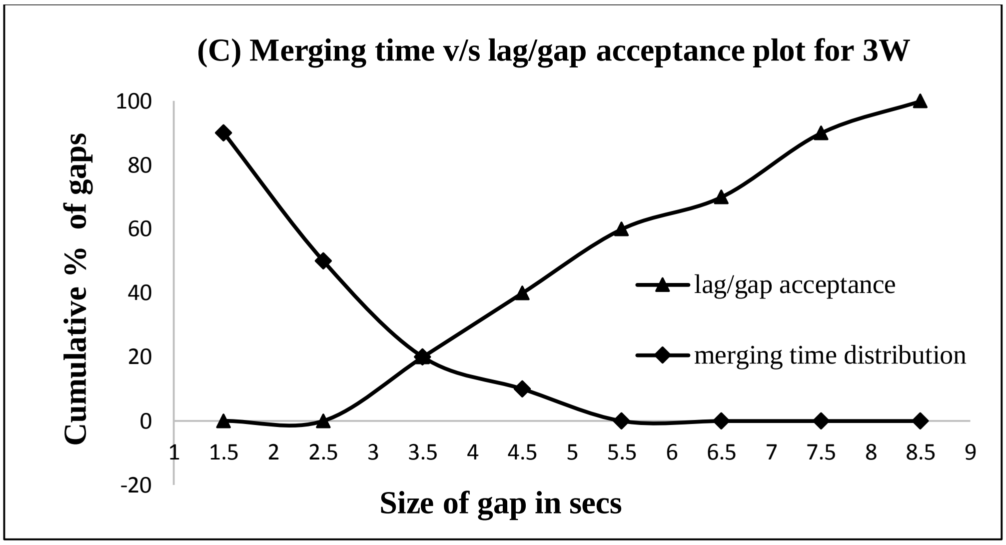
Figure 6.2 Cumulative Stochastic Distribution of Gaps by Macroscopic Probability Equilibrium Method for 3 wheelers and Sport Utility Vehicles respectively

Figures 6.1 and 6.2 represents the cumulative probability distribution of accepted gaps, critical gaps and rejected gaps in seconds for the four motorized modes considered to account for mixed traffic conditions in Indian context. The stochastic plots signifies or verifies that the critical gaps is neither less than the rejected gaps nor greater than those accepted by a U-turn driver. All the above figures gives the description of the Macroscopic Probability Equilibrium Method by Ning Wu considering critical gap estimation.

6.1.2 INAFOGA Method







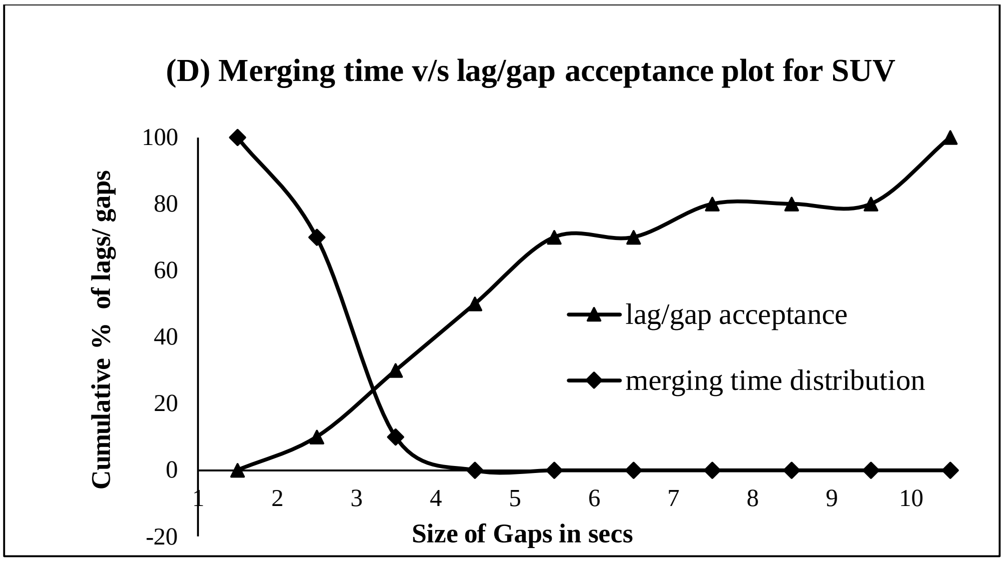
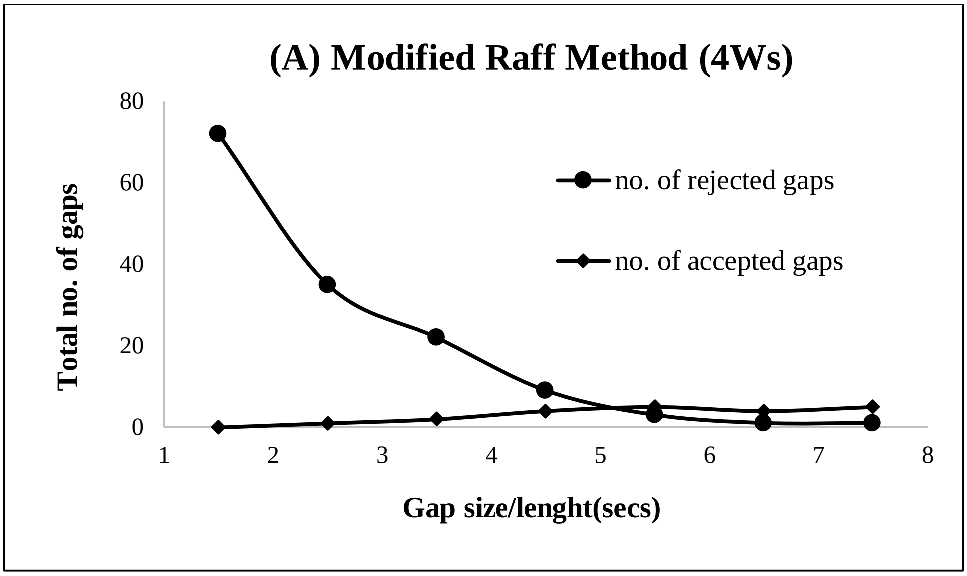
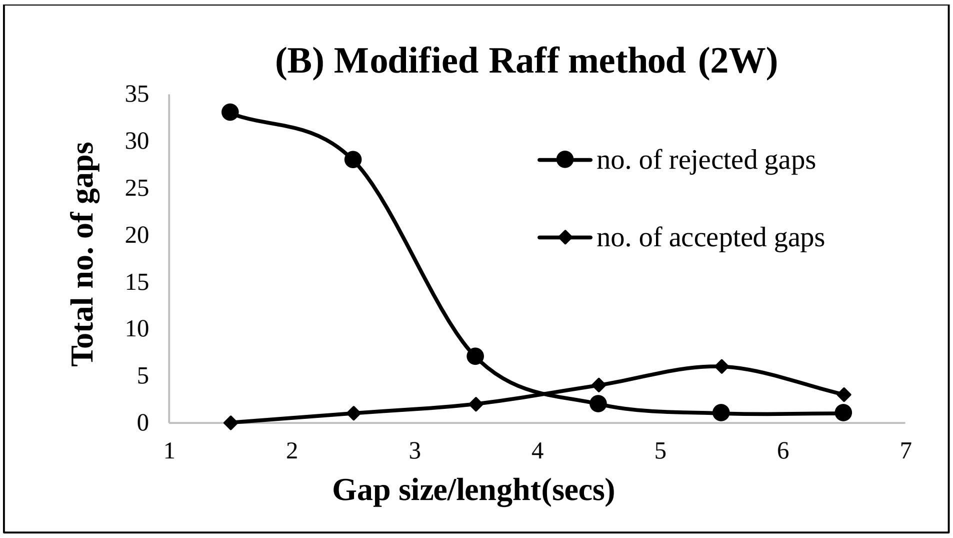


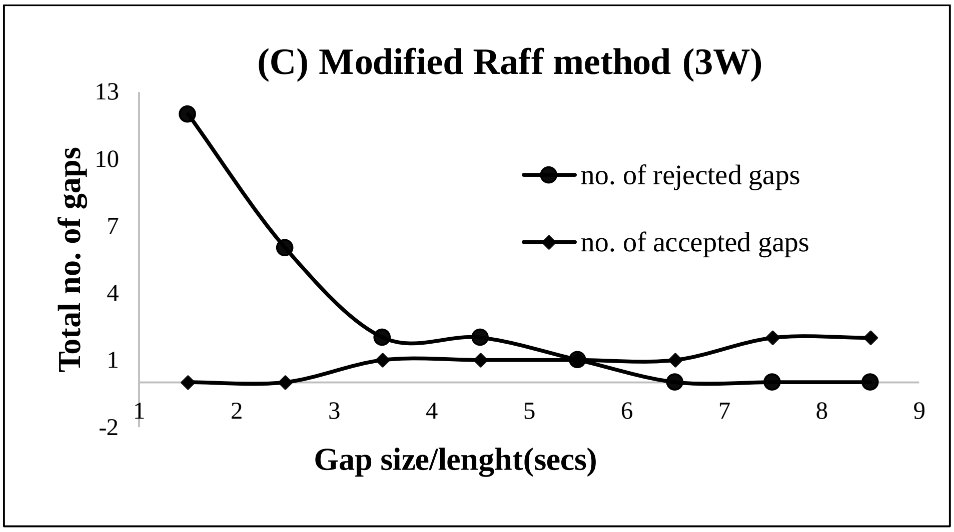
Figure 6.3 Lag/Gap Acceptance versus Merging Time Frequency Distribution plots for (A) 4Ws, (B) 2Ws, (C) 3Ws and (D) Sport Utility Vehicles

Figure 6.3 shows the cumulative percentage plots versus gap sizes for the four different modes considered to account for mixed traffic conditions. All accepted lags and gaps are binned with gap size of specific intervals of 0.5 seconds to plot along with merging times of U-turn vehicles in “INAFOGA” method. The projection of the point of intersection between the lag/gap acceptances and merging time cumulative frequency distributions on the Gap size axis gives the desired value of the critical gap.

6.1.3 Modified Raff method







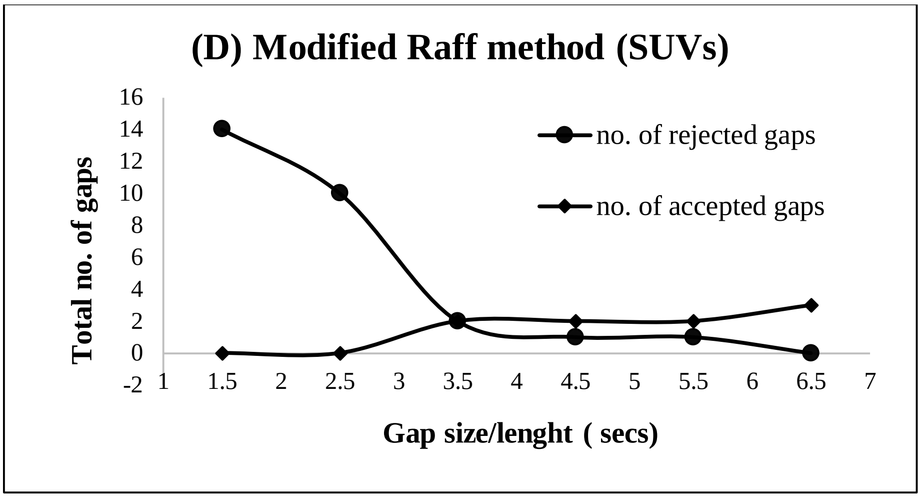
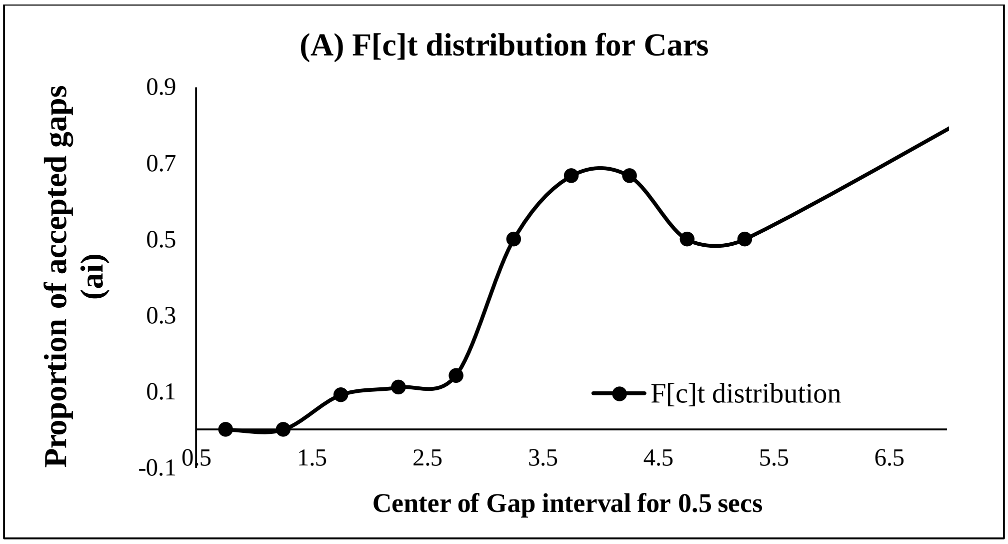
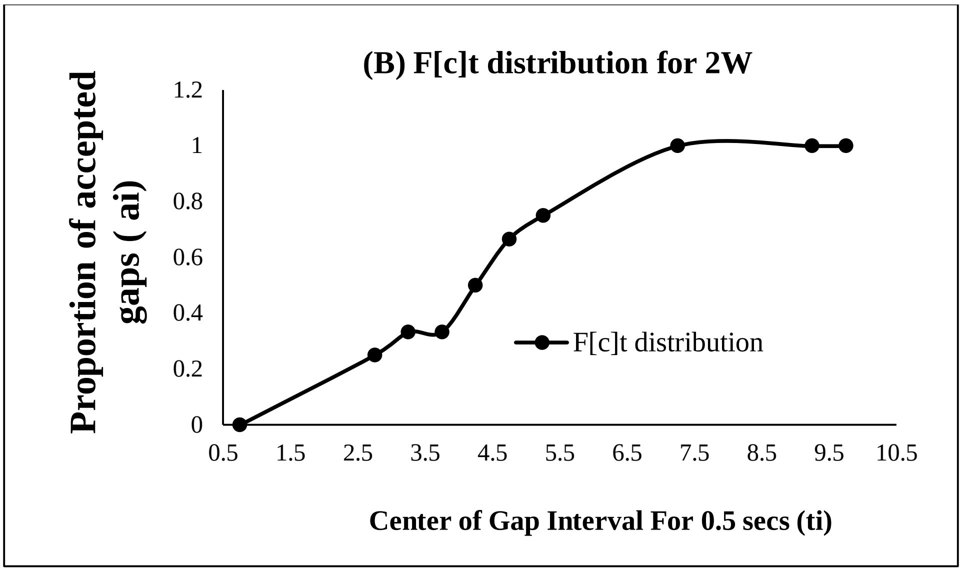


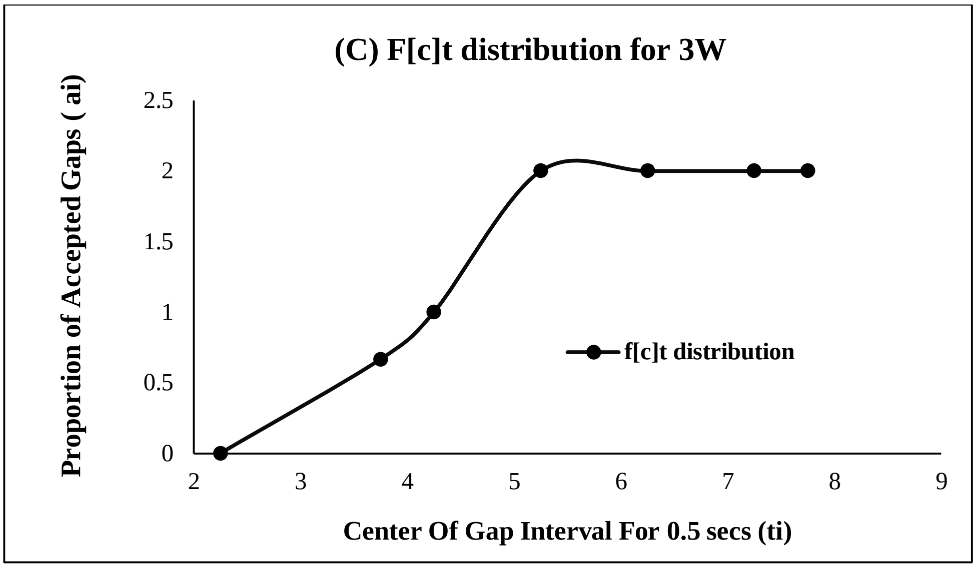
Figure 6.4 Cumulative Frequency Distribution plots for no. of accepted and rejected gaps for (A) 4Ws, (B) 2Ws, (C) 3Ws and (D) Sport Utility Vehicles

Modified Raff Method follows the old technique of counting the number of accepted and rejected gaps and then plotting them for the total no. of gaps versus gap size/length in seconds in the y and x axes respectively. Figure 6.4 gives a graphical description of estimating critical gaps for several motorized U-turn vehicles following Modified Raff Method. The projection of the point of intersection between the no. of accepted and rejected gaps plotted lines on the Gap length axis gives the critical gaps for a certain mode.

6.1.4 Harders Method







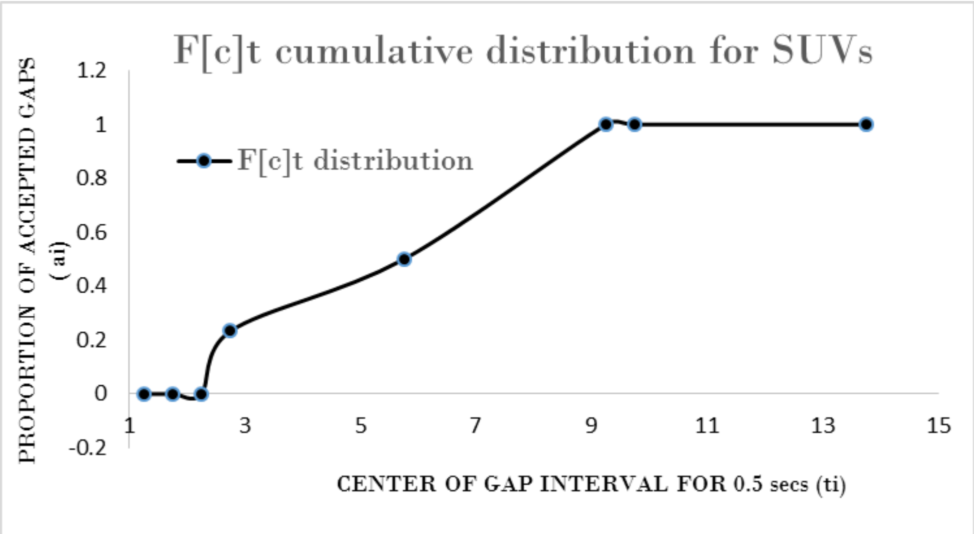


Figure 6.5 Stochastic Cumulative frequency distribution of Critical Gaps as per proportion of accepted gaps for (A) 4Ws, (B) 2Ws, (C) 3Ws and (D) Sport Utility vehicles (SUVs)

All the figures as represented in section 6.1 of this chapter deals with the estimation of U-turn critical gaps. Figures 6.1 and 6.2 certifies that the distribution of critical gaps lies in between the rejected and accepted gap distribution for all the four motorized modes considered in this study. Figure 6.3 shows cumulative frequency plots of accepted lags and gaps with merging times for various modes for “INAFOGA” method. Coming to modified Raff method, the count of accepted and rejected gaps are plotted for gap sizes of 0.25 seconds and the intersection point projected on the gap size axis gives the critical gap for a particular mode. Harders method finds out critical gaps by plotting proportion of accepted gaps with the bin size of 0.25 secs i.e. the center of gap 0.5 secs.

Table 5.1 lists the critical gap values for U-turn vehicles at selected median opening sites of Rourkela and Bhubaneshwar considered in this study. After going through the table it can judged that the critical gap values obtained using “INAFOGA” method are comparatively higher than other existing methods used in this research. Therefore certain comparisons between different critical gap values obtained using the methods is probable. And due to this fact, a One-way ANOVA test is performed for finding the significance in comparison between the critical gap values obtained by different methods.

6.2 Estimated Critical Gap values for Nine Median Opening Sections

The following are the estimated values of critical gaps obtained from the existing empirical methods for the four motorized modes of transport considered in this study. The symbol ** in the table 6.1 indicates no or nil samples for a particular mode obtained from a particular method.

Table.6.1 Critical Gap Values for U-turns by Existing Methods

Median Opening Section no.	Vehicle Type	Critical gap(s) for U-turns at Median Opening by Existing methods			
		Prob. Equi.	INAFOGA	Mod. Raff	Harders
1 (Rourkela Institute of Management Studies, kacheri road, Rourkela)	Car	2.85	3.375	3.19	3.38
	Motorized 2-Wheeler	4.38	4.50	3.75	4.75
	3-Wheeler	3.68	3.45	3.50	4.50
	Sport Utility Vehicles	2.73	3.15	3.50	5.75
2(Panposh Road Rourkela)	Car	3.54	4.50	5.52	4.25
	Motorized 2-Wheelers	2.52	4.75	5.40	3.25
	3-Wheelers	**	5.15	4.50	4.25
	Sport Utility Vehicles	**	6.00	4.75	5.75
3 (Pal Heights towards J.V., Bhubaneshwar)	Car	2.84	3.00	5.00	6.25
	Motorized 2-Wheeler	3.08	3.20	4.00	6.75
	3-Wheeler	3.25	3.50	5.50	5.25
	Sport Utility Vehicles	2.60	3.25	3.50	4.75
4(C.S. Poor HPCL Petrol Pump, Bhubaneshwar)	Car	3.45	5.15	4.50	3.30
	Motorized 2-Wheeler	4.15	4.75	2.35	3.38
	3-Wheeler	3.75	4.80	3.15	4.15
	Sport Utility Vehicles	2.75	3.45	5.60	5.15
5(Near Patia IOCL Petrol Pump, Bhubaneshwar)	Car	3.45	6.05	5.55	4.75
	Motorized 2-Wheeler	2.87	5.25	3.95	5.00
	3-Wheeler	4.75	5.15	2.75	4.00
	Sport Utility Vehicles	3.38	4.75	3.45	4.25
6(Eastern Railway Headquarters, Bhubaneshwar)	Car	4.25	5.55	4.15	3.75
	Motorized 2-Wheeler	2.75	3.15	2.25	2.75
	3-Wheeler	3.68	3.75	2.98	5.15
	Sport Utility Vehicles	**	4.8	3.38	2.75
7(SBI Colony, Bhubaneshwar)	Car	3.45	4.15	2.85	3.75
	Motorized 2-Wheeler	5.14	5.85	3.15	4.15
	3-Wheeler	2.75	3.25	5.00	5.50
	Sport Utility Vehicles	3.97	4.00	4.15	3.75
8(Near Kalinga Stadium Bhubaneshwar)	Car	2.85	3.25	5.55	3.00
	Motorized 2-Wheeler	5.00	6.00	3.30	5.75
	3-Wheeler	4.15	5.55	2.25	4.15
	Sport Utility Vehicles	3.00	2.75	2.75	5.15
9(Near Regional College of Management, Bhubaneshwar)	Car	2.85	3.04	3.55	2.75
	Motorized 2-Wheeler	3.75	4.15	4.15	4.45
	3-Wheeler	4.15	5.25	3.45	5.75
	Sport Utility Vehicles	3.15	4.55	4.15	4.75

6.3 One way ANOVA tests for Significance of Variance between Existing Methods for the Median Opening Sections in SPSS

6.3.1 One Way ANOVA

One way ANOVA (Analysis of Variance) is used in statistical analysis for comparison of means of more than two groups or levels of an independent variable. Anova is used to find significant relations between various variables.

One of these assessments (between gathering change) is the measure of the impact of the independent variable joined together with error variance. The other estimate (inside gathering change) is of error variance itself. The F-ratio is the proportion of, between groups and within group variance. In special cases when null hypothesis is rejected i.e. when significant different still lies Post Hoc analysis tests like Scheffe and Tukey tests are further performed for a stricter determination of significance. The Anova test is a parametric test which assumes homogeneity of variances between groups along with the assumption of normally distributed population/sample. The procedure of Anova involves the derivation of two separate assessments of population variance from the information sets.

Table.6.2 One-way ANOVA Tables for Comparison between Different Methods

Descriptives								
Critical Gap values								
	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Prob. Equi	32	3.2854	.67872	.18824	2.8752	3.6955	2.52	4.76
INAFOGA	32	3.6312	.50187	.13919	3.3279	3.9344	3.00	4.50
Mod. Raff	32	4.4892	.82928	.23000	3.9881	4.9904	3.19	5.52
Harders	32	5.1146	.97787	.27121	4.5237	5.7055	3.38	6.75
Total	128	4.1301	1.03911	.14410	3.8408	4.4194	2.52	6.75

Test of Homogeneity of Variances			
Critical Gap values			
Levene Statistic	D.f 1	D.f 2	Sig.
2.667	3	125	p=.058

One-way ANOVA					
Critical Gap values					
	Sum of Squares	D.f	Mean Square	F-ratio	Sig.
Between Groups	26.790	3	8.930	15.158	p=.000
Within Groups	28.278	124	.589	---	---
Total	55.067	127	---	---	---

Critical Gap values			
Tukey Test for Assumption of Equal Variances			
Existing Methods	N	Subset for alpha = 0.05	
		1	2
Prob. Equi.	32	---	3.2854
INAFOGA	32	3.6312	---
Mod. Raff	32	4.4892	---
Harders	32	---	5.1146
Means for groups in homogeneous subsets are displayed.			
a. Uses Harmonic Mean Sample Size = 32.000.			

After conducting the above tests it can be ascertained that there can be significant comparison are possible between:

- Macroscopic Probability Equilibrium and “INAFOGA” methods
- Harders and Macroscopic Probability Equilibrium method
- “INAFOGA” and Harders method
- Modified Raff and Probability Equilibrium Method

Conducting further analysis it was ascertained that only “INAFOGA” method can be compared with both Harders and Macroscopic Probability Equilibrium methods. Hence, the critical gap values obtained from “INAFOGA” method are indeed comparable to existing methods used under homogeneous traffic conditions.

6.4 Paired Sample t-tests for Critical Gap Values Obtained Using Existing Methods for the median opening sections in IBM-SPSS

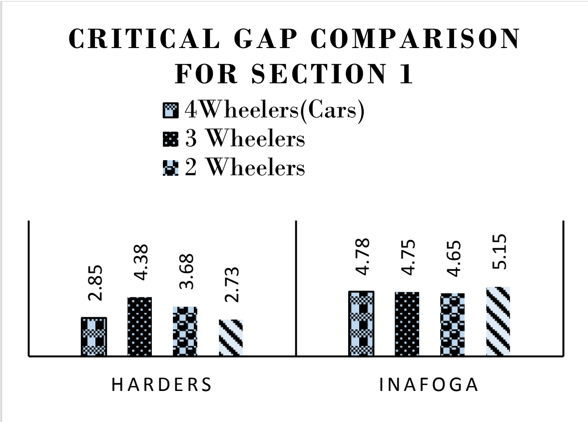
6.4.1 Paired Sample t-statistic test between HARDERS & "INAFOGA" methods for all modes

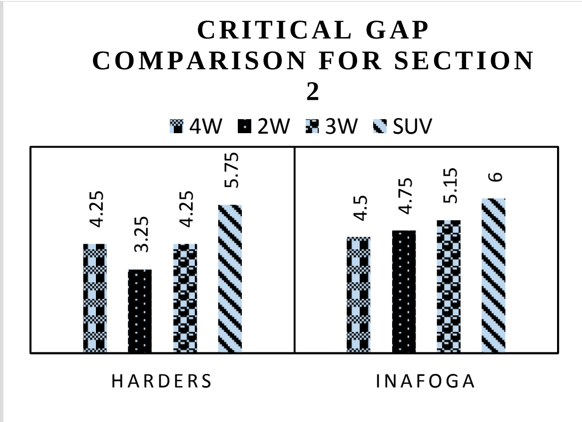
TABLE 6.3 STATISTICAL DETAILS OF THE PAIRED SAMPLES T-TEST FOR HARDERS AND "INAFOGA" METHODS

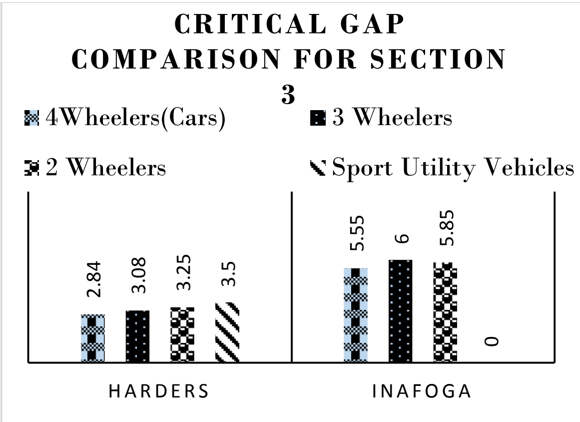
Paired Samples Statistics for ALL Modes					
		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	HARDERS	4.5163	40	.90157	.31875
	INAFOGA	4.031250	40	.4292331	.1517568

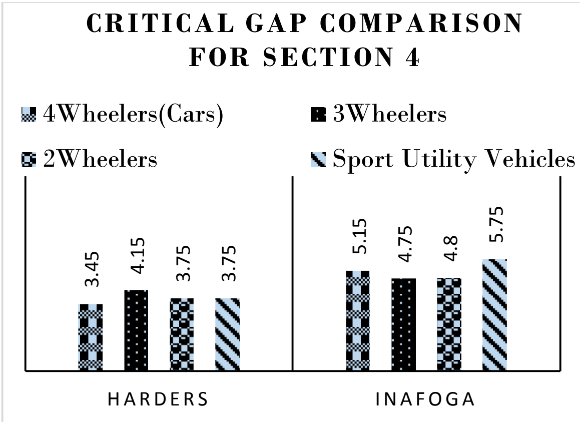
Paired Samples Correlations				
		N	Correlation	Sig.
Pair 1	HARDERS & INAFOGA	40	.872	.005

Paired Samples Test for ALL Modes									
		Paired Differences					t-statistic	D.f	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	HARDERS - INAFOGA	.48500	.5676518	.2006952	.0104312	.9595688	2.417	39	.046


CRITICAL GAP COMPARISON FOR SECTION 1
4Wheelers(Cars)
3 Wheelers
2 Wheelers
2.85
4.38
3.68
2.73
4.78
4.75
4.65
5.15
HARDERS
INAFOGA


CRITICAL GAP COMPARISON FOR SECTION 2
4W
2W
3W
SUV
4.25
3.25
4.25
5.75
4.5
4.75
5.15
6
HARDERS
INAFOGA


CRITICAL GAP COMPARISON FOR SECTION 3
4Wheelers(Cars)
3 Wheelers
2 Wheelers
Sport Utility Vehicles
2.84
3.08
3.25
3.5
5.55
6
5.85
0
HARDERS
INAFOGA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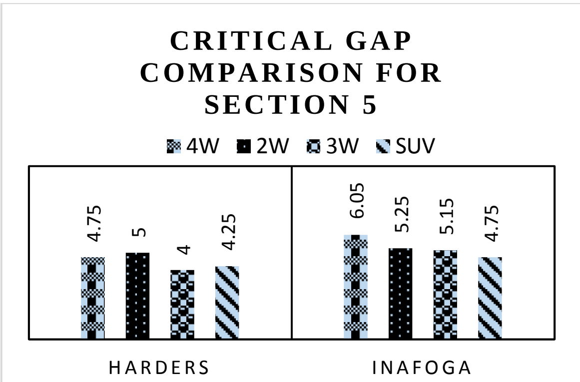
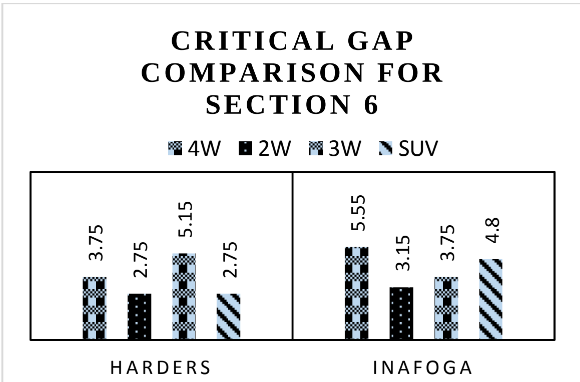
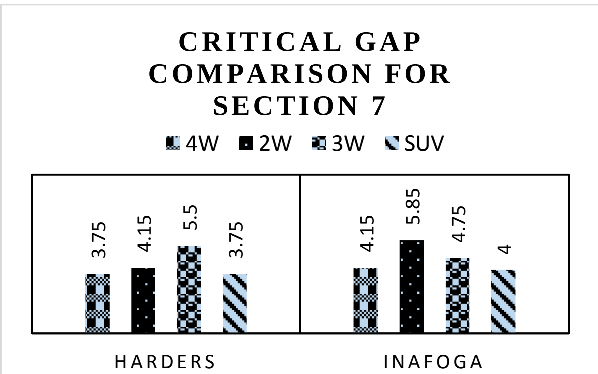
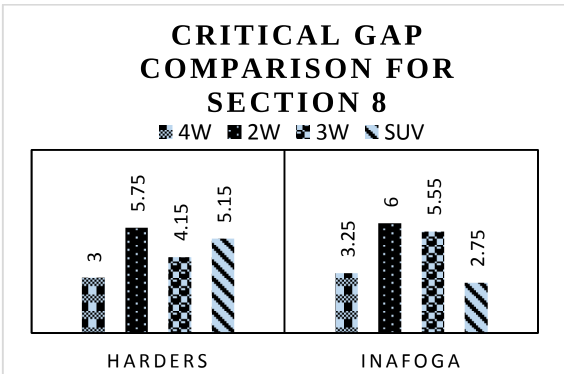
4Wheelers(Cars)
3Wheelers
2Wheelers
Sport Utility Vehicles
3.45
4.15
3.75
3.75
5.15
4.75
4.8
5.75
HARDERS
INAFOGA


CRITICAL GAP COMPARISON FOR SECTION 5
4W
2W
3W
SUV
4.75
5
4
4.25
6.05
5.25
5.15
4.75
HARDERS
INAFOGA


CRITICAL GAP COMPARISON FOR SECTION 6
4W
2W
3W
SUV
3.75
2.75
5.15
2.75
5.55
3.15
3.75
4.8
HARDERS
INAFOGA


CRITICAL GAP COMPARISON FOR SECTION 7
4W
2W
3W
SUV
3.75
4.15
5.5
3.75
4.15
5.85
4.75
4
HARDERS
INAFOGA


CRITICAL GAP COMPARISON FOR SECTION 8
4W
2W
3W
SUV
3
5.75
4.15
5.15
3.25
6
5.55
2.75
HARDERS
INAFOGA

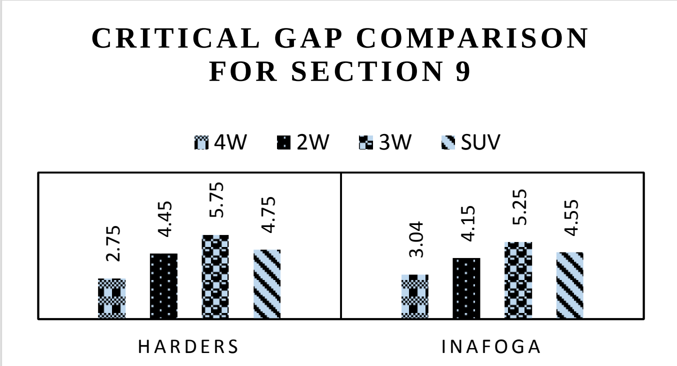


Figure.6.6. Cluster Bar Plots for critical gap comparison of nine different sections under mixed traffic

Table 6.3 and Figure 6.6 depicts the comparison of critical gaps for several motorized modes in SPSS. The cluster bar plots shown in fig 5.1 portrays the fact that “INAFOGA” method gives greater values of critical gaps with respect to Harders method. The t-statistic value of 2.417 and two-tailed significance of (Sig.) 0.046 ($p<0.05$) validates that an extreme comparison between the two techniques is indeed feasible. For, some of the motorized modes like Sport Utility vehicles (SUVs) and motorized tree-wheelers (3Ws), critical gap values corresponding to sections 8, 3 and 2 were more for Harders. This in fact can explain the inability of “INAFOGA” method to address the driver behaviour of the above mentioned modes.

6.4.2 Paired Sample t-statistic test between Macroscopic Probability Equilibrium & “INAFOGA” methods for all modes

TABLE 6.4 STATISTICAL DETAILS OF THE PAIRED SAMPLE T-TEST FOR COMPARISON BETWEEN PROBABILITY EQUILIBRIUM – “**INAFOGA**” METHODS IN IBM SPSS 22.0

Descriptive Statistics:

		N	Mean	Standard deviation	Standard mean error	Median
"Critical Gaps by Equilibrium Method"		24	3.63375	0.92416	0.18864	3.75

"Critical Gaps by INAFOGA"		24	4.87625	1.25488	0.25615	5.15
	Difference	24	-1.2425	1.54491	0.31535	-1.375
	Overall	48	4.255	1.25806	0.18159	4.25

T-statistics:

	t -Statistic	**Degrees of freedom**	**Two-tailed Significance**
	-3.94004	23	6.52801E-4

Null Hypothesis: mean1-mean2 = 0

Alternative Hypothesis: mean1-mean2 <> 0

At the 0.05 level, the contrast of the population means is fundamentally not quite the same as the test distinction (0) ##

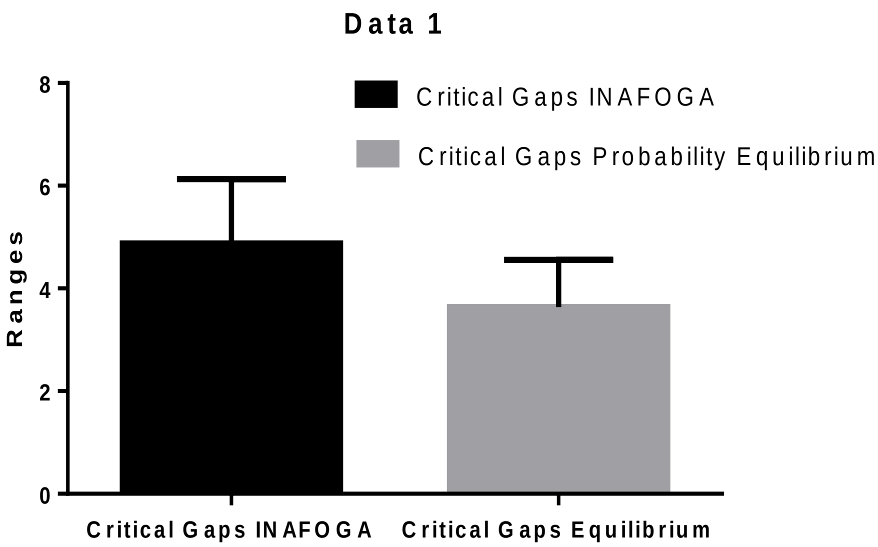
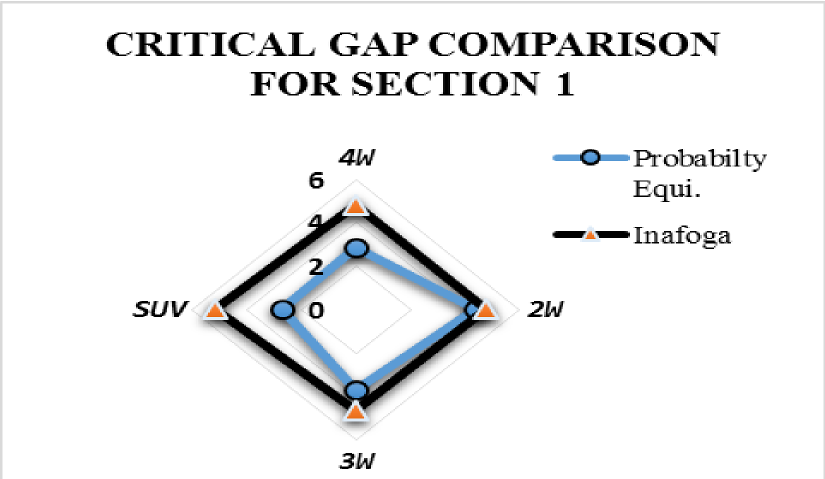
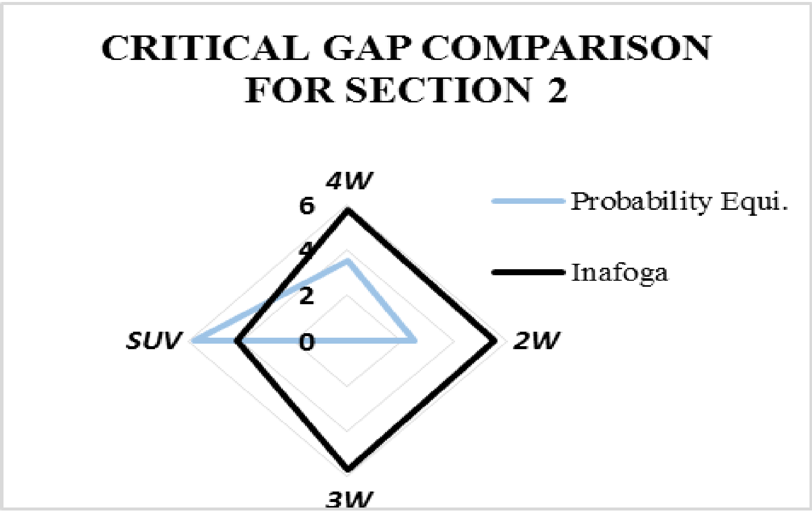


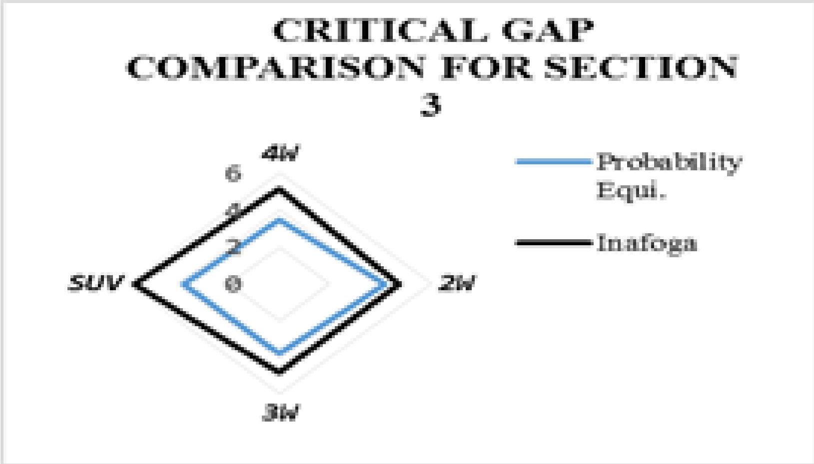
Figure 6.7 Box Range plots for Critical Gap Comparison between “INAFOGA” and Macroscopic probability Equilibrium Methods

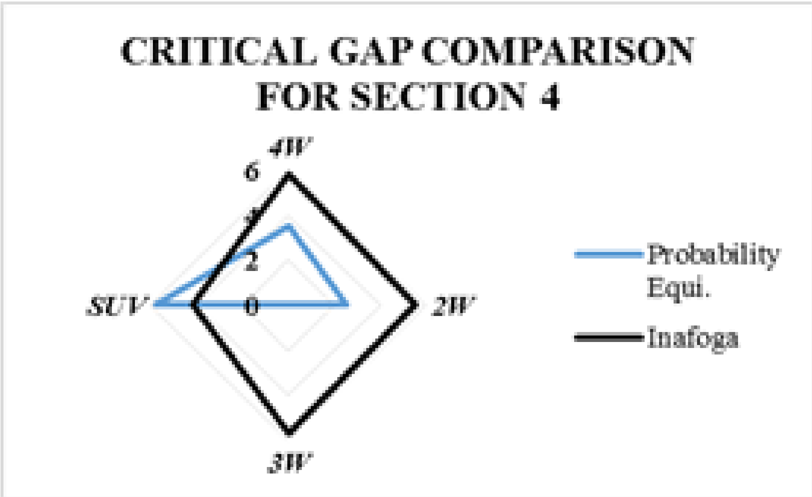
Table 6.4 and Figure 6.7 depicts the descriptive statistics, t-statistics and box-range plots showing the significant comparison of critical gap values between

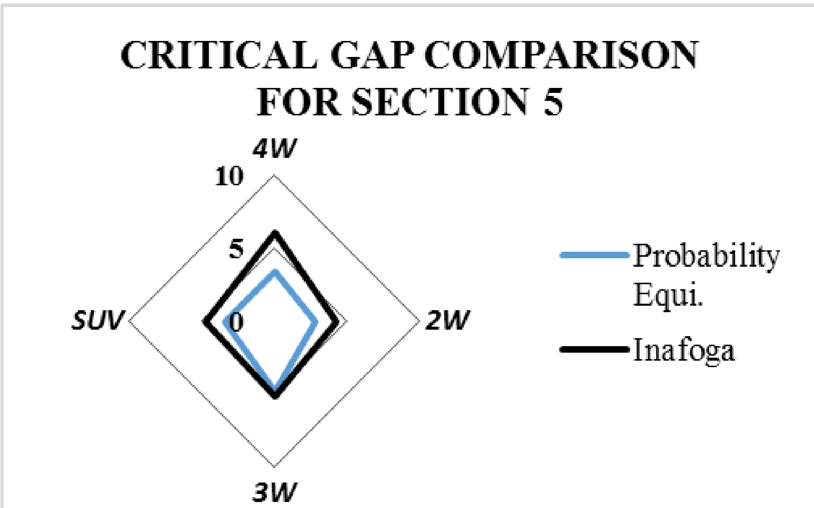
Macroscopic Probability Equilibrium and INAFOGA methods. The negative t-statistic and lower two-tailed significance values in Table 6.4 (t-value = -3.94; p-value=0.00065) indicates extremely significant comparison. The gap between the upper whiskers of the critical gap ranges of the two different boxes (dark black being the INAFOGA box with upper value 6.04 secs and light black being the Probability Equilibrium box with upper value of 4.75 secs) having a difference of more than 2.5 seconds. The total no. of samples participated are 48 with median values of 3.75 and 5.15 seconds. The paired sample t-test and box-range plotting performed in OriginLab verifies the significance of comparisons.






CRITICAL GAP COMPARISON FOR SECTION 3
4W
2W
3W
SUV
6
4
2
0
Probability Equi.
Inafoga


CRITICAL GAP COMPARISON FOR SECTION 4
4W
2W
3W
SUV
6
4
2
0
Probability Equi.
Inafoga


CRITICAL GAP COMPARISON FOR SECTION 5
4W
2W
3W
SUV
10
5
0
Probability Equi.
Inafoga

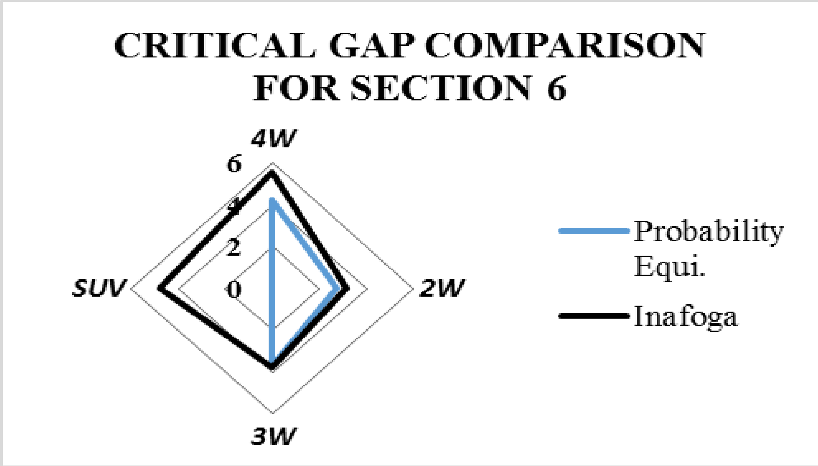


Figure 6.8. Radar Plots for critical gap comparison between the methods for six different sections under mixed traffic

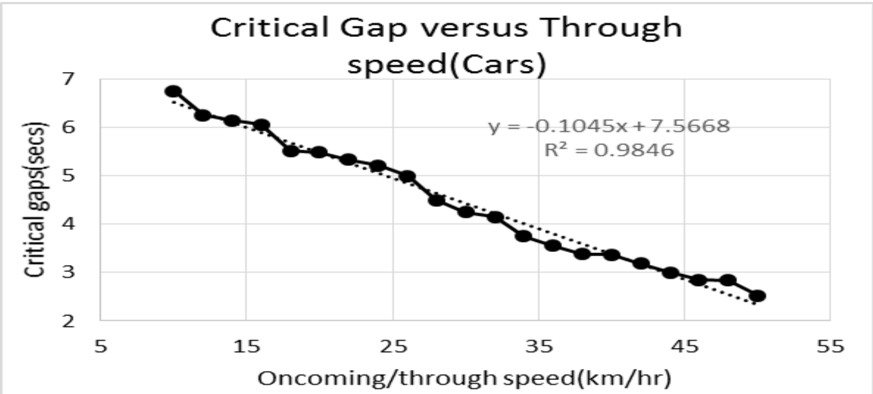
Figure 6.8 gives a pictorial overview of the difference in critical gap values for the first six median opening sections listed in Table 5.2 of chapter 5 of this report. The reason behind neglecting the rest of the three sections (i.e. Section 7, 8 and 9) is the failure of the critical gap values in passing the t-test (p-values >0.05) for comparison. As clearly seen from figure 6.8 critical gap values for Sport Utility Vehicles obtained using Probability Equilibrium method are more compared to INAFOGA method for the median opening sections 2 and 4. Thus, it is clear that INAFOGA method shows a shortcoming in predicting gap acceptance characteristics of a U-turn SUV driver whereas for the rest of the modes the method yield satisfactory results.

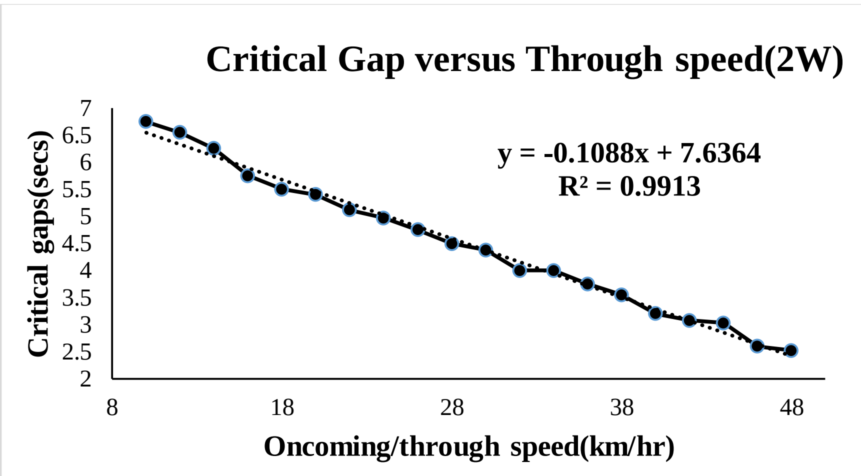
6.5 Regression Models and Empirical Relationships of Traffic and Driver Behaviour Characteristics with Critical Gap

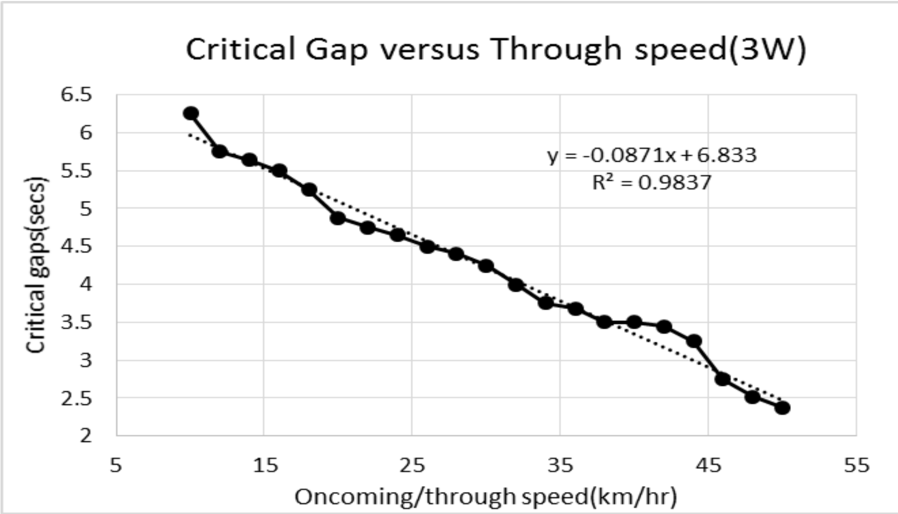
The goal/objective of the topic encrypted above is to study the effect of driver waiting time, conflicting traffic flow and speed on a U-turn driver's critical gap at a median opening. Driver waiting time was simulated by processing of the raw data collected from the field in a demuxer software. Speed and flow of the conflicting traffic was calculated from the video-image processing of the raw data. . Flow was converted to PCU/hr. from vehicles/second as per the Indian stipulations given in IRC: 86-1983.

Four motorized modes of transport were considered to account for the mixed traffic situations in India. . IBM SPSS 22.0 and MS-Excel 13 were used for finding the empirical relationships between driver waiting time, conflicting traffic speed and flow with critical gaps separately. Curve fitting in IBM SPSS were done to model the relationships. Power regression variation was observed between waiting time and critical gap for all the three modes except for three wheelers (3W). Best curve fit were obtained as linear regression for the relation between conflicting traffic speed and critical gap and an exponential one between flow and critical gap considering all the four modes. The results thus obtained from the simulation are tabulated and discussed in this study.

6.5.1 Critical Gap versus Conflicting/ Through Traffic Speed Model under Mixed Traffic







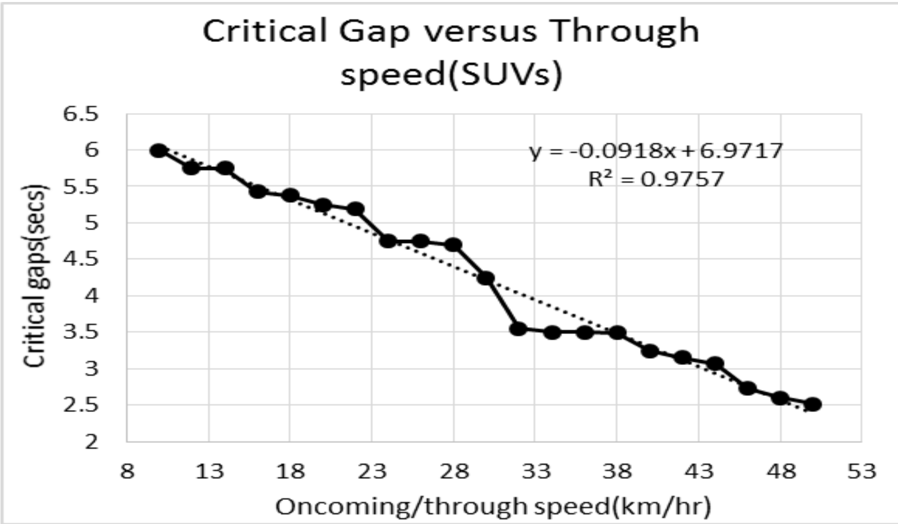


Figure 6.9 Regression Models showing dependence of Conflicting Traffic Speed (Kmph) on U-turn driver's Critical Gaps under Mixed Traffic

Figure 6.9 shows the critical gap versus through/conflicting speed (kmph) plots for the four motorized modes. With the increase in the speed of the through/conflicting traffic vehicles there is linear decay in the U-turn critical gap acceptances. As observed from the video data, the above fact is true due to the fact that any U-turn driver avoids shorter gaps and are literally afraid of accepting gaps prior to high speed vehicles.

6.5.2 Relationship between Critical Gaps-Waiting Times-Conflicting Traffic flows for SUVs:

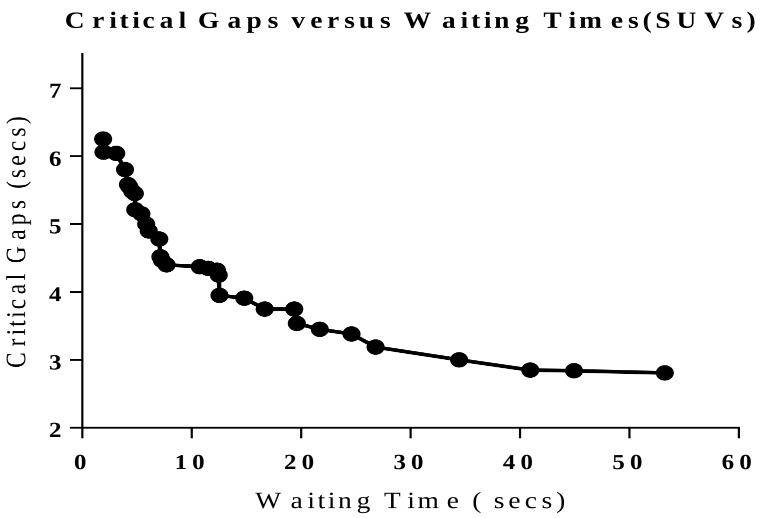
Table.6.5 Statistical and Parametric Details of the Regression Model for SUVs

	Waiting Times for SUVs	**Conflicting Traffic flow**
Number of Points	35	35
Degrees of Freedom	33	33
Reduced Chi-Square	1.86415	0.00617
Residual Sum of Squares	61.51691	0.20367
Adj. R-Square	0.89749	0.94613
Fit Status	Succeeded(100)	Succeeded(100)

Parameters:

		Value	**Standard Error**
Waiting Times for SUVs	a	90.73186	12.31586
	b	-1.94159	0.12079
Conflicting Traffic flow	a	8.69222	0.9283
	b	-2.17058	0.09702

Equation for Non-linear Curve fit: y= a. x^b



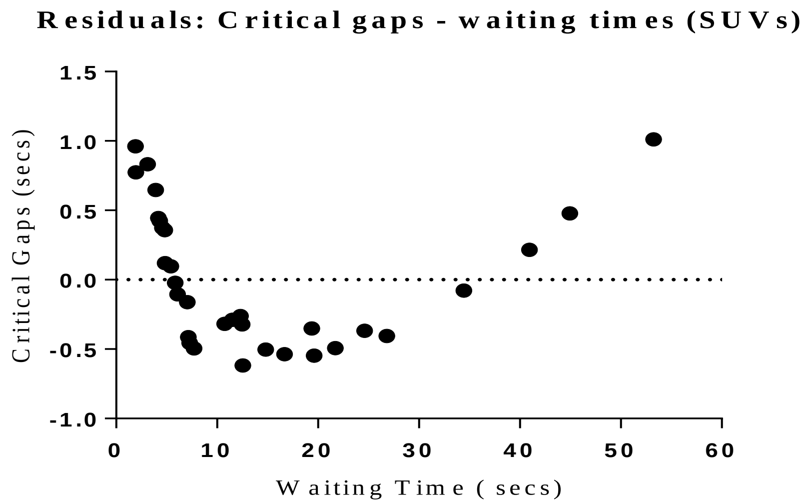
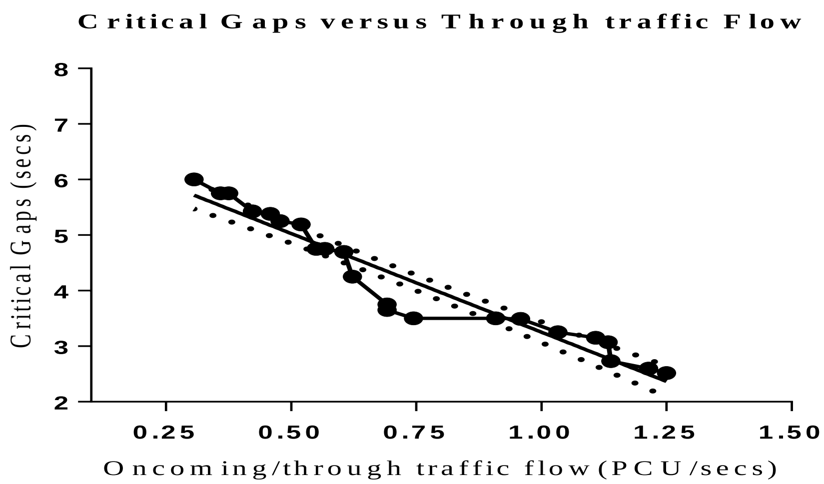


Figure 6.10 Variation of Critical Gaps with increasing Waiting times for Sport Utility Vehicles

Table 6.5 and figure 6.10 shows the descriptive statistics, un-standardised and standardised parameters, critical gap-waiting times plot and residual plot for critical gap-waiting times for Sport Utility Vehicles. A power regression variation is obtained for the dependence of driver waiting times on U-turn SUVs critical gaps. The difference between the observed value and predicted value of the critical gaps gives the residuals for the regression equation. As seen from the residuals plot, a U-shaped dispersion around the dotted horizontal line shows random data variation and non-linear fit (in this case power fit) for the Sport Utility vehicle drivers.



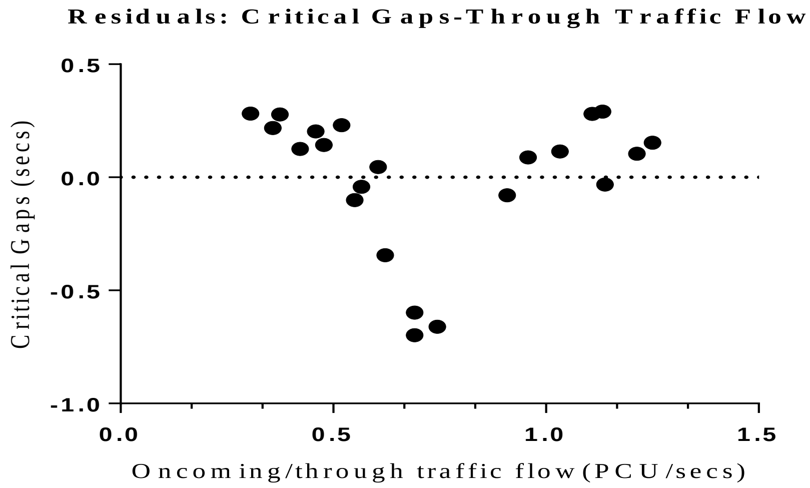


Figure 6.11. Effect of Through Traffic flow (PCU/secs) on U-turn Critical Gaps for SUVs

Table 6.5 and figure 6.11 shows the regression parameters and power fit plot between cr Itical gaps and oncoming/through traffic flow. The U-shaped dispersion of the residuals show a non-linear fit i.e. a power of the relationship/model.

6.5.3 Relationship between Critical Gaps-Waiting Times-Conflicting Traffic flows for 4Ws:

Table.6.6 Statistical and Parametric Details of the Regression Model for 4Ws

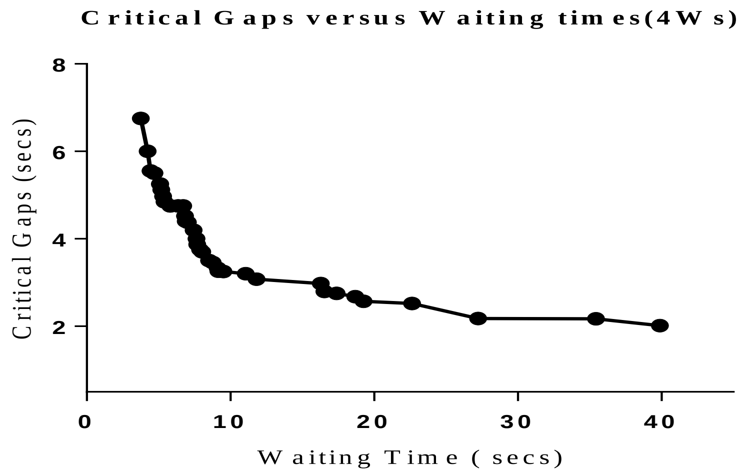
	Waiting Times for 4Ws	**Conflicting Traffic flow**
Number of Points	35	35
Degrees of Freedom	33	33
Reduced Chi-Square	3.35856	0.00431
Residual Sum of Squares	110.83242	0.14236
Adj. R-Square	0.9804	0.96235
Fit Status	Succeeded(100)	Succeeded(100)

Parameters:

		Value	**Standard Error**
Waiting Times for 4Ws	a	2028.66474	260.20164
	b	-3.64321	0.11121
Conflicting Traffic flow	a	12.77773	1.30515
	b	-2.19807	0.0812

Model Summary:

	a		b		Statistics	
	Value	Standard Error	Value	Standard Error	Reduced Chi-Square	Adj. R-Square
Waiting Times for 4W	2028.66474	260.20164	-3.64321	0.11121	3.35856	0.9804
Conflicting Traffic flow	12.77773	1.30515	-2.19807	0.0812	0.00431	0.96235



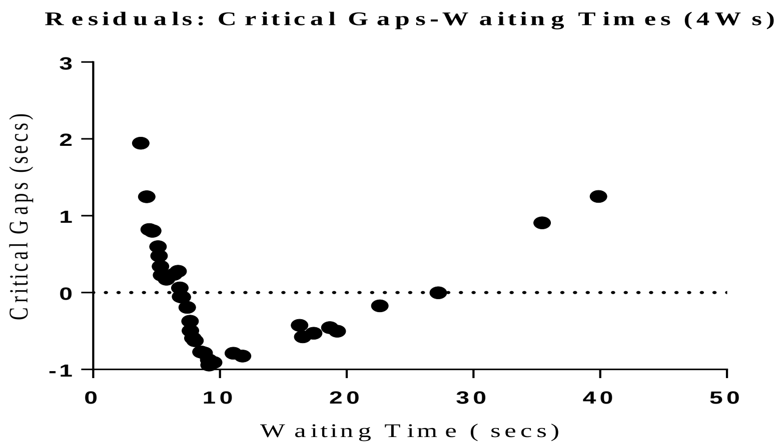
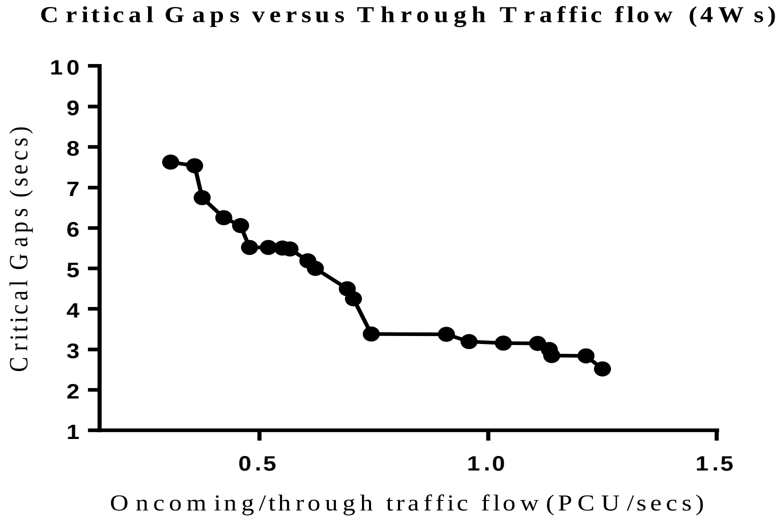


Figure 6.12.Plot of Waiting Times versus U-turn Critical Gaps for Cars (4Ws)

Table 6.6 and figure 6.12 represents the regression model for the waiting times versus U-turn critical gaps plot. The U-shaped residuals in the plot shows perfect non-linear fit for 4 wheelers (in this case a power regression). The adjusted R-squared value of the power fit is 0.9804 which can be considered very significant and good fit.



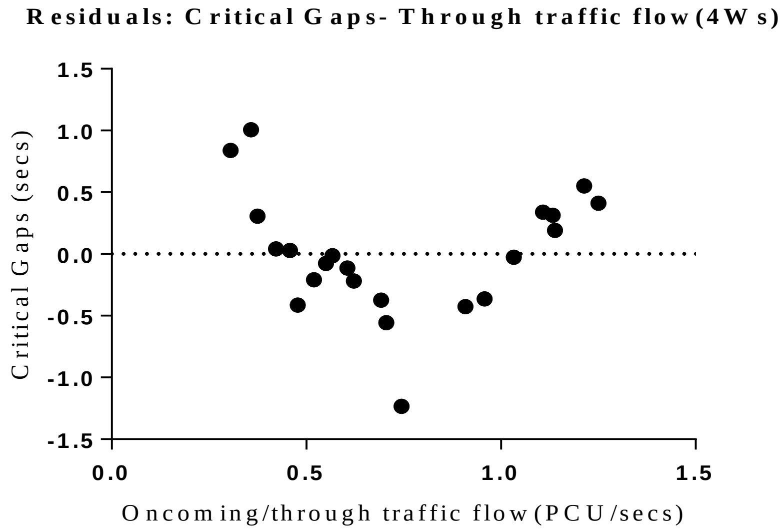


Figure.6.13.Effect of Oncoming Traffic flow (PCU/secs) on U-turn 4Ws Critical Gaps

The somewhat scattered U-shaped residuals around the dotted horizontal mean line of the Critical gaps (secs) – through/conflicting traffic flow (PCU/secs) plot for the 4 wheeler drivers indicate a mildly significant power regression between the variables considered in this model. The residual plot signifies the difference between the observed and predicted values of critical gaps of 4 wheelers in this model. Table 6.6 and figure 6.13 shows the statistical, parametric details and critical gaps-through traffic flow plot for the 4 wheeler drivers.

6.5.4 Relationship between Critical Gaps-Waiting Times-Conflicting Traffic flows for 2Ws:

Table.6.7 Statistical and Parametric Details of the Regression Model for 2Ws

Statistics:

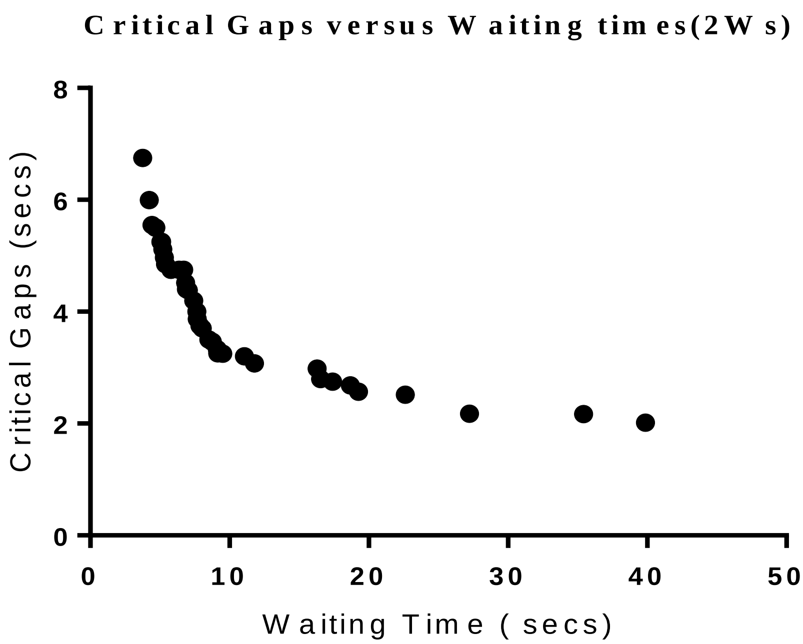
	Waiting Times for 2Ws	**Conflicting Traffic flow**
Number of Points	38	38
Degrees of Freedom	36	36
Reduced Chi-Square	2.84117	0.00545
Residual Sum of Squares	102.28196	0.19602
Adj. R-Square	0.96052	0.95126
Fit Status	Succeeded(100)	Succeeded(100)

Parameters:

		Value	**Standard Error**
Waiting Times for 2Ws	a	201.08958	16.69673
	b	-2.39514	0.08572
Conflicting Traffic flow	a	4.991	0.37474
	b	-1.7747	0.07118

Model Summary:

	a		**b**		**Statistics**	
	Value	Standard Error	Value	Standard Error	Reduced Chi-Square	Adj. R-Square
Waiting Times for 2Ws	201.08958	16.69673	-2.39514	0.08572	2.84117	0.96052
Conflicting Traffic flow	4.991	0.37474	-1.7747	0.07118	0.00545	0.95126



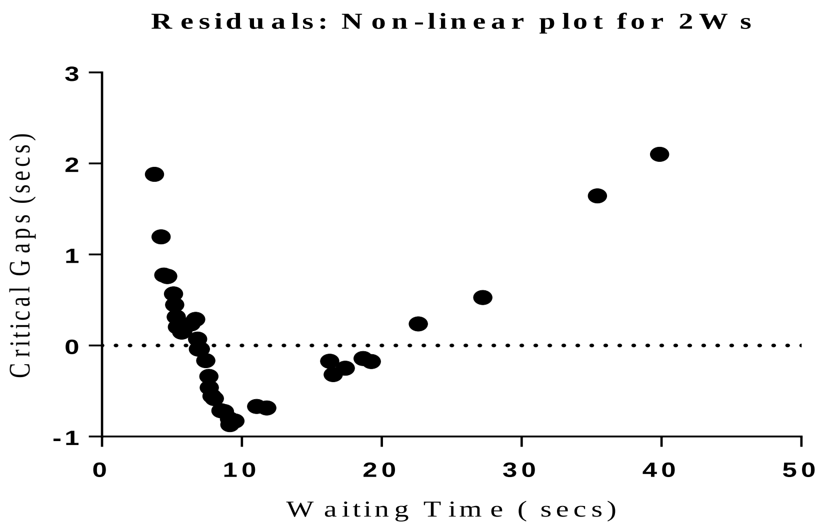
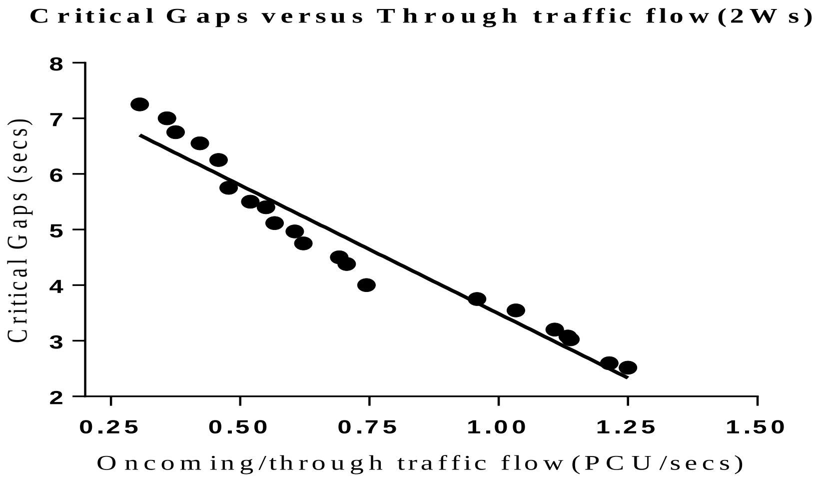


Figure 6.14.U-turn Critical Gap versus Driver Waiting Times plot for 2 wheelers

Table 6.7 and figure 6.14 shows the statistical, parametrical and graphical distributions of the regression model for the dependence of U-turn 2 wheeler vehicle critical gaps on the driver waiting times at or near the close vicinity of the median openings. The U-shaped residuals around the dotted horizontal line shows an extremely significant(R-squared = 0.96052) non-linear power regression fit of critical gaps with increasing waiting times at the selected median opening sites considered in this study.



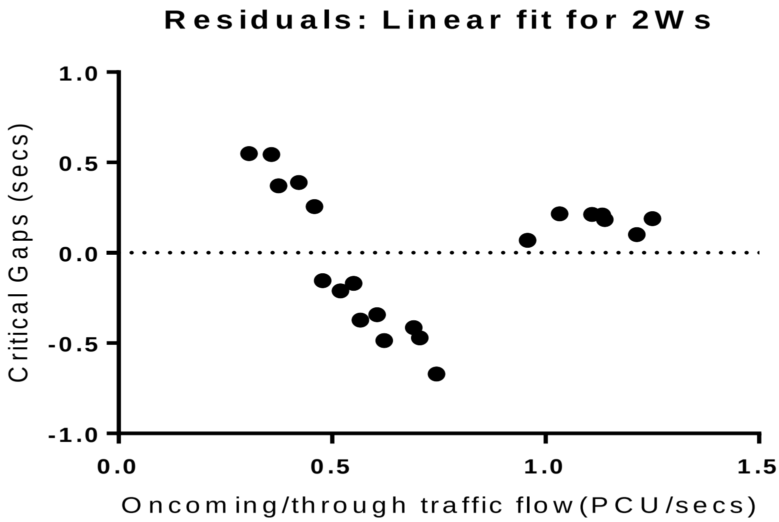


Figure 6.15. Linear variation of U-turn 2W Critical Gaps with Increasing Through/Oncoming Traffic flow in PCU/seconds

Table 6.7 and Figure 6.15 shows the critical gap versus through traffic flow regression details for two-wheelers. The adjusted R-squared value comes to be 0.95126 which denotes best fit for the linear regression model in Origin LAB. The somewhat distributed residual plot around the horizontal line signifies that the fit is indeed linear in nature. Thus, there is a linear decrease in U-turn critical gaps with increase in the no. of vehicles per second per lane on the oncoming/through street.

6.5.5 Relationship between Critical Gaps-Waiting Times-Conflicting Traffic flows for 3Ws:

Table.6.8 Statistical and Parametric Details of the Regression Model for 3Ws

Statistics:

	Waiting Times for 3Ws	Conflicting Traffic flow
Number of Points	38	38
Degrees of Freedom	36	36
Reduced Chi-Square	0.53026	0.00556
Residual Sum of Squares	19.08946	0.20031
Adj. R-Square	0.9392	0.95019
Fit Status	Succeeded(100)	Succeeded(100)

Parameters:

		Value	Standard Error
Waiting Times for 3Ws	a	66.6899	6.32586
	b	-1.87138	0.08089
Conflicting Traffic flow	a	8.8796	0.8802
	b	-2.12433	0.08662

Model Summary:

	a		b		Statistics	
	Value	Standard Error	Value	Standard Error	Reduced Chi-Square	Adj. R-Square
Waiting Times for 3Ws	66.6899	6.32586	-1.87138	0.08089	0.53026	0.9392
Conflicting Traffic flow	8.8796	0.8802	-2.12433	0.08662	0.00556	0.95019

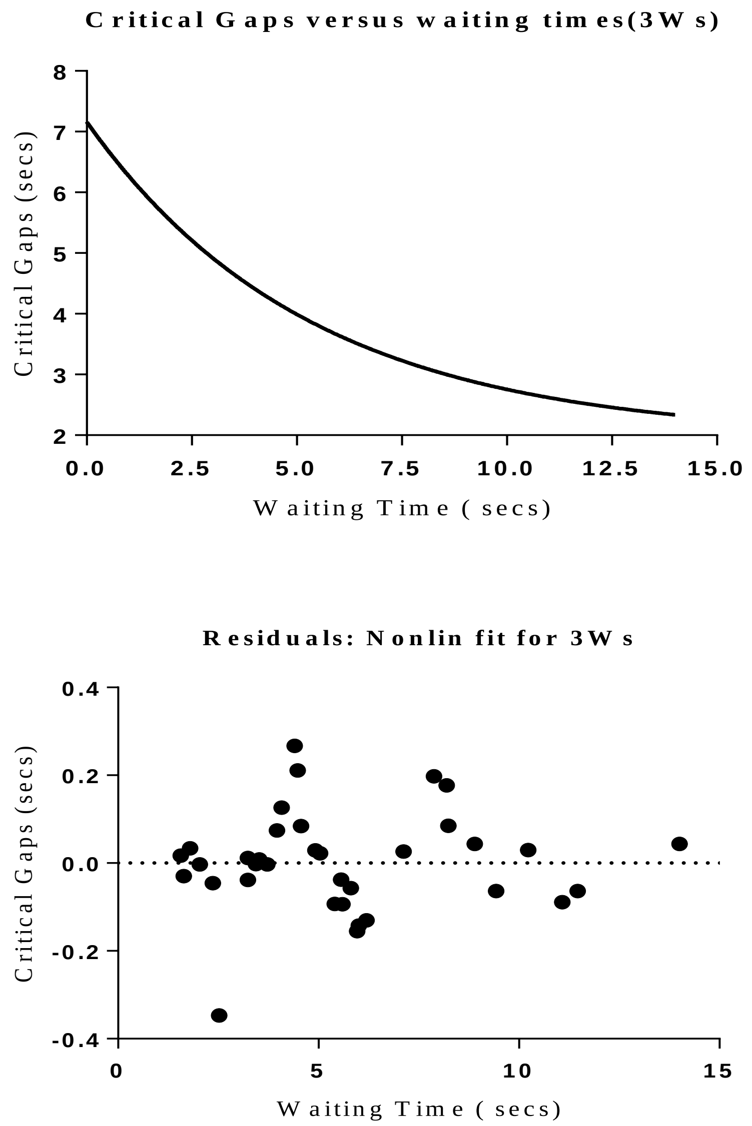
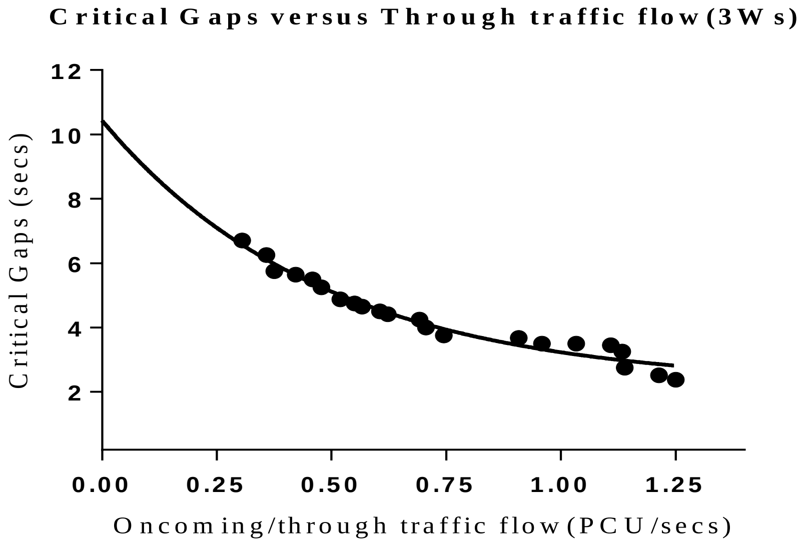


Figure 6.16. Non-linear Power Regression of Critical gaps with Waiting Times for 3 wheelers

The three minor U-shaped residuals around the horizontal line in figure 6.16 demarcates that the exponential fit of the critical gaps with increasing waiting times is indeed valid. Observing closely, the residuals are somewhat evenly dispersed in small U-patterns around the mean horizontal line of the residual plot. But, this doesn't suggest that the fit may have been linear. Instead it confirms that the non-linear fit of critical gap-waiting time values for 3 wheelers is not a robust but a least-square fit. Summarising the model, the exponential decay regression fit(R-squared = 0.9392) shows weak dependence of critical gaps on waiting times for U-turn 3 wheelers.



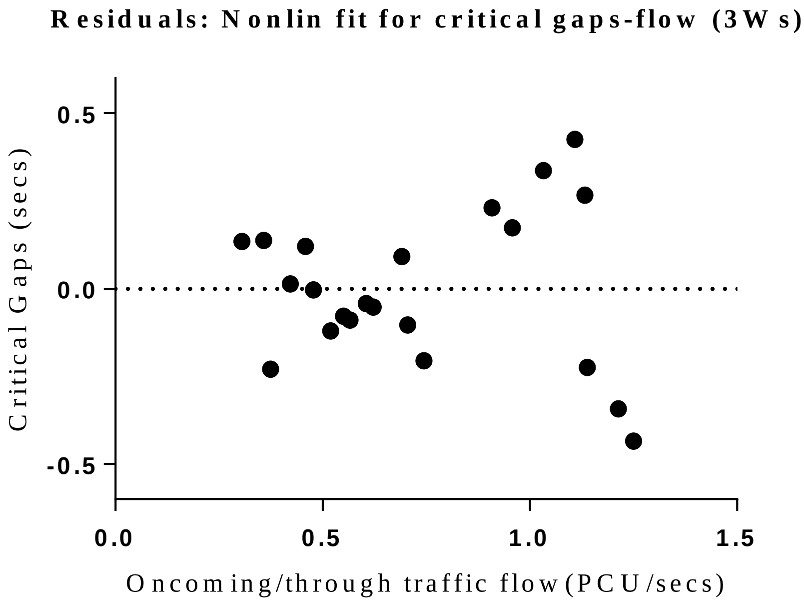


Figure 6.17.Power Regression Variation of through Traffic Flow (PCU/secs) with 3W Critical gaps

The unevenly scattered residuals around the mean predicted values of residuals as shown by the horizontal line in the residual plot for the non-linear fit predicts that the fit may be linear but in order to substantiate all the samples at a time, a power fit has been made. With increase in the conflicting traffic there is a power decrease in critical accepted gaps for three wheelers. The R-squared value of 0.95019 is considered sufficiently significant as obtained for table 6.8 and the fit shown in figure 6.17

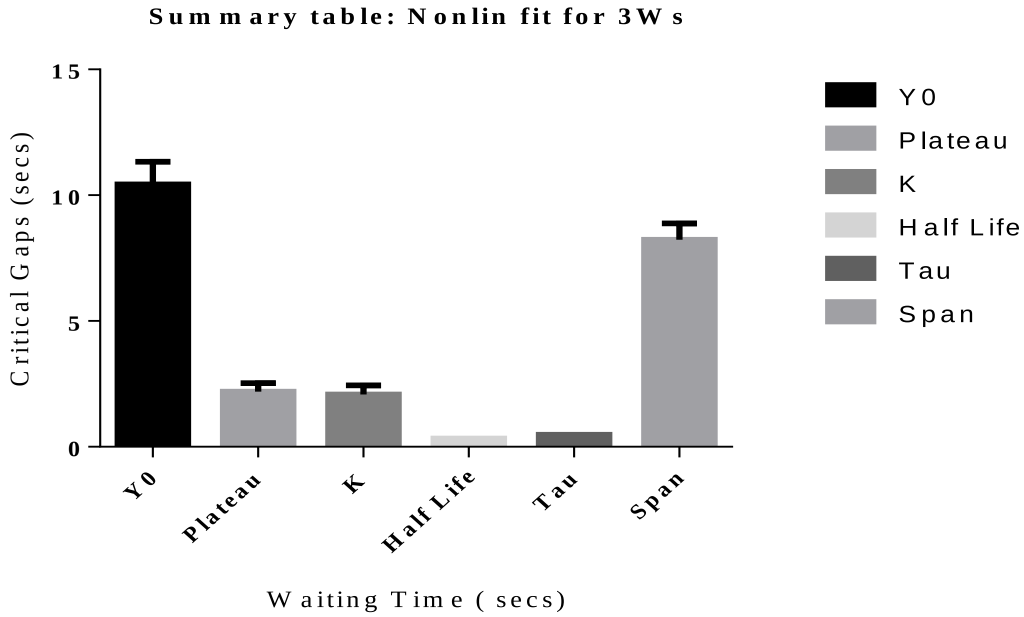
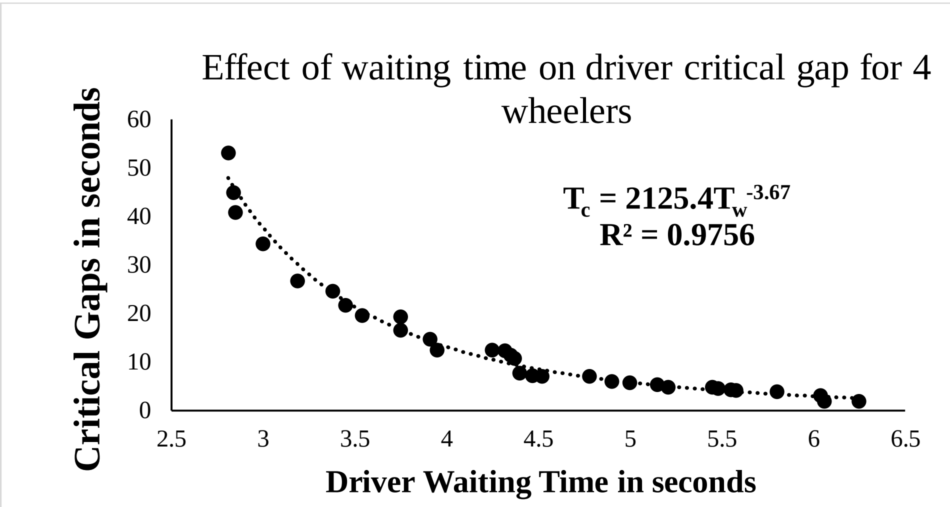
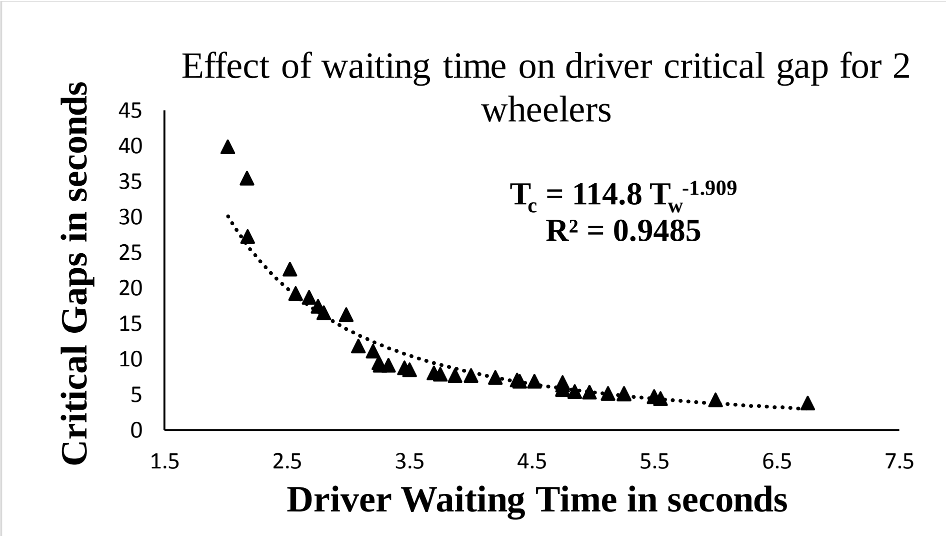
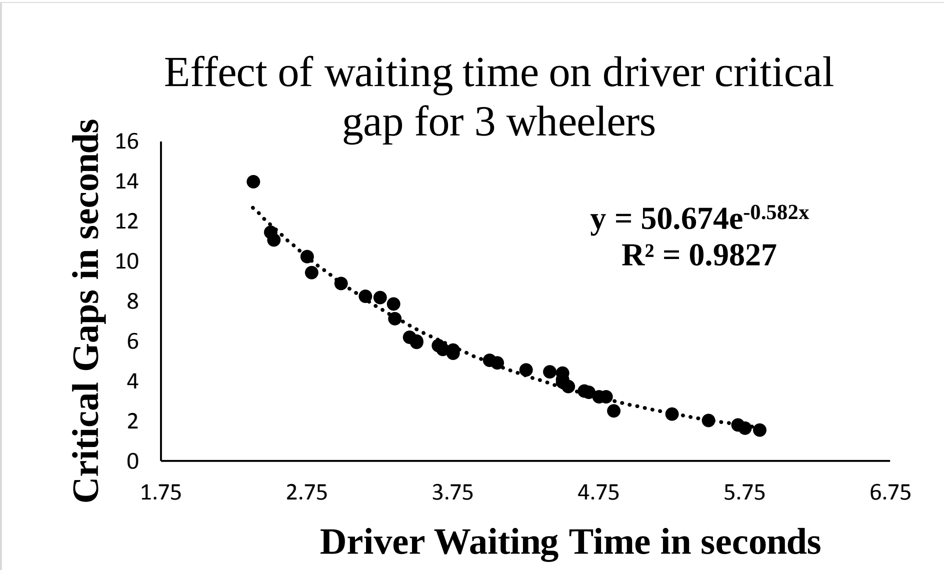


Figure 6.18 Box Range plots for the non-linear fit for 3 wheelers







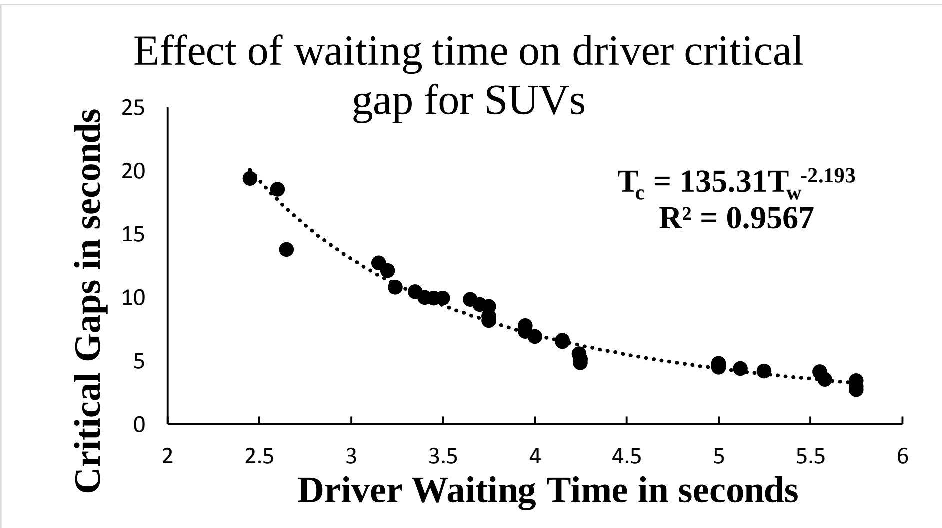


Figure 6.19 Regression equation plots for effect of driver waiting times on critical gaps under homogeneous traffic situations

Summary of the regression models and empirical relationships can represented in a tabular manner as follows:

Table.6.9 Summary of the Regression Models Developed in the Chapter

Variables Considered	**Type of Relationship/Model with Expressions**			
	4 wheelers	***2 wheelers***	***3 wheelers***	***SUVs/MUVs***
Critical gaps – Waiting Time	$T_c = 2028.64\ e^{-3.642.T_w}$ $R^2 = 0.9804$ Exponential Regression	$T_c = 201.089\ T_w^{-1.7747}$ $R^2 = 0.96052$ Power Regression	$T_c = 66.68.T_w^{-1.87138}$ $R^2 = 0.93920$ Power Regression	$T_c = 90.732T_w^{-1.942}$ $R^2 = 0.89749$ Power Regression
Through/Conflicting traffic speed – critical gaps	T_c=7.5668-0.1045. V_{th} R^2=0.9846 Linear regression	T_c=7.6364-0.1088. V_{th} R^2=0.9913 Linear regression	T_c=6.833-0.0871. V_{th} R^2=0.9837 Linear regression	T_c=6.9717-0.0918. V_{th} R^2=0.9757 Linear regression
Critical gaps – conflicting/through traffic flow	T_c= 12.77.$Q_{th}^{-2.19807}$ R^2=0.96235 Power Regression	T_c= 4.991-1.7747.Q_{th} R^2=0.95126 Linear Regression	T_c= 8.8796 $Q_{th}^{-2.12433}$ R^2=0.95019 Power Regression	T_c= 8.692 $Q_{th}^{-2.1706}$ R^2=0.94613 Power Regression

The above tables and figures show the dependence of traffic characteristics like flow (PCU/secs) and speed in kmph on U-turn driver's gap acceptance. Four motorized modes of transportation were considered to account for the mixed traffic conditions in India. The regression models were developed equally in tools like IBM-SPSS, OriginLab 9.1 and Graph PAD Prism/InSTAT for all the four modes. The R-squared values for these models varied from 0.93920 to 0.9913 with a mean R-squared value of 0.94745. Driver behaviour related characteristic like Waiting Time has also been regression modelled in OriginLab and Graph Pad with U-turn critical gaps with adjusted R-squared values of 0.9468-0.9674. For the conflicting traffic flow-critical gap model, 2 wheelers showed linear regression while the other modes like 2 wheelers. 3 wheelers and Sport Utility vehicles showed power regression. For conflicting/through traffic speed-critical gap model, all the U-turn modes selected from the median opening sites showed a linear regression with critical gap as the dependent and speed as the independent variable. Driver waiting time-critical gap model yield exponential regression for 4 wheelers while power regression for three other modes. In an earlier study by Yang, Zhou, Lu and Nelson in 2010 where they derived regression models for relating conflicting speed with U-turn critical gap, the authors after conducting regression tests found very low t-statistic value of 1.66, indicating insignificant variation of speed with critical gaps. But, this study contradicts the above statement and shows significant linear decay of critical gaps with increasing through/oncoming stream speed (adjusted R-square = 0.9757, t-statistic = 5.78). The authors Lu and Nelson also studied the effect of average total delay (sec/veh) on critical gaps. According to them, as gap duration increases, the risk in entering the opening decreases, and therefore the probability of accepting the gap increases. Also, long waiting times/delay that drivers may experience during facing a gap, causes them to lose patience and are willing to take a greater risk. Thus, they have a higher probability of accepting a gap. The authors concluded that gaps lower than 2 seconds are independent of waiting times. But, in this study the latter statement has also been proven wrong and it may be concluded on behalf of this study that there is significant dependence of waiting times on gaps accepted and critical gaps irrespective of the gap duration depending upon the type of vehicle driver only.

6.6 ANOVA Modelling between Accepted Gaps & Merging Time in terms of Gender for 2 Wheelers

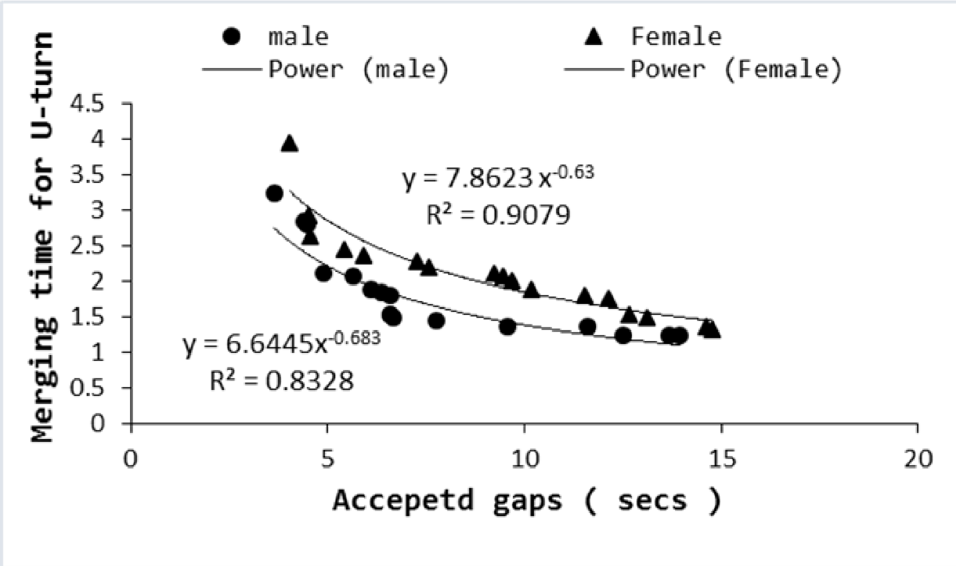


Figure 6.20.. Accepted Gaps- Merging Time Variation for Male and female Drivers

Gaps accepted by a U-turn driver depends upon the merging time i.e. the time taken by the U-turn vehicle in clearing the median opening or in other words to merge with the conflicting or through traffic flow. An ANOVA model was formulated in IBM SPSS 22.0.1 for finding out the relationship of merging time of a two wheeler driver with its corresponding gap accepted for clearing the median opening. Both male and female 2 wheeler drivers were participated in the formulation. During extraction of data it was observed that in about 80% of sample sizes, female accepted gaps were lesser compared to male ones. The observation included about 38 male and 23 female 2W drivers. After conducting the model testing, results indicated power variation of merging time with accepted gaps for both the sexes. The model was solely regression in nature with a power variation of accepted gaps for dedicated values of merging times.

The model summary is as follows:

For Male Drivers:

Model Summary			
R	R Square	Adjusted R Square	Std. Error of the Estimate
.913	.893	.892	.129
The independent variable is Male Accepted			

ANOVA					
	Sum of Squares	D.f	Mean Square	F	Sig.
Regression	1.248	1	1.248	74.719	.000
Residual	.251	15	.017		
Total	1.499	16	---		
The independent variable is Male Accepted					

Coefficients					
	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
In(Male Accepted)	-.683	.079	-.913	-8.644	.000
(Constant)	6.644	1.051		6.323	.000
The dependent variable is in (Male Merging).					

For Female Drivers:

Model Summary			
R	R Square	Adjusted R Square	Std. Error of the Estimate
.953	.908	.902	.089
The independent variable is female accepted.			

ANOVA					
	Sum of Squares	D.f	Mean Square	F-ratio	Sig.
Regression	1.167	1	1.167	147.815	.000
Residual	.118	15	.008		
Total	1.285	16	---		
The independent variable is female accepted.					

Coefficients					
	Unstandardized Coefficients		Standardized Coefficients	t-statistic	Sig.
	B	Std. Error	Beta		
In(female accepted)	7.8544	.444	.935	10.205	.000
(Constant)	-.0643	.062		2.095	.004
The dependent variable is in (female Merging).					

Thus, from the above models the merging time for male drivers can be related to the gaps accepted by the same ones is as follows:

$$\textbf{Merging Time for Male Drivers, } T_m = 6.6445\,(T_A)^{-0.683}$$

Where, T_A = Gaps Accepted by the driver in secs

Also, for the female 2 wheeler U-turn vehicles, merging time can be related to the gaps accepted by the same ones is:

$$\textbf{Merging Time for Female drivers, } T_m = 7.8623\,(T_A)^{-0.63}$$

Substituting the values of T_A in the above equations one can easily understand that the time required for merging with the through/conflicting traffic flow is more than a male driver.

6.7 Chapter Summary

The data collected from the cities of Rourkela and Bhubaneshwar were extracted to find the necessary decision variables needed to estimate critical gaps. The critical gaps were estimated using the different existing methods along with "INAFOGA" method using the new concept of "Merging Behavior" introduced in this study. This chapter shows certain plots for the estimation techniques of critical gaps using the methods selected for analysis. The critical gap values thus obtained were analyzed for comparison between the four motorized modes considered. A methodological comparison between four of the existing methods are also represented in this chapter. Tools like IBM-SPSS, Origin Lab 9.1 and Graph PAD Prism, InSTAT were used for the analysis of the critical gap values. The chapter also shows the different regression and ANOVA empirical models between critical gaps and several traffic and driver behavior related characteristics under Indian mixed traffic situations. Critical gaps were modelled with through traffic flow and speed, driver waiting time or average delay and accepted gaps were modelled for females and males with merging times for 2 wheeler drivers.

CHAPTER 7

CONCLUSIONS AND DISCUSSIONS

7.1 Conclusions in General on Estimation of Critical gaps

- For every sections selected for analysis, the critical gap values for a 4-wheeler was found to be more than that for a 2 wheeler driver
- The above step contradicted for the road leading to C.S. Poor for critical gap values obtained by Modified Raff method
- Values of critical gaps obtained by "INAFOGA" method are about 18-41 % higher than other values of critical gaps obtained by existing methods
- This research initiative introduces the new concept of merging behavior for estimating critical gaps of U-turn drivers at median openings on multi-lane roads under mixed traffic flow in Indian context.
- Merging time indicates the complete merging maneuver of U-turn vehicles at median openings.
- . In this study, data was collected in the form of video recording from six median openings on 4-lane and 6-lane roads located in the urban regions of Bhubaneshwar and Rourkela cities situated in the eastern part of India.

7.1.1 Conclusions regarding the Comparison between Harders and "INAFOGA" Methods

Two existing methods available in previous literatures were used to estimate the critical gap values. Using the "INAFOGA' concept for data extraction, estimation of critical gaps for U-turns at median openings under mixed traffic conditions have been done in this study. The only limitation found while studying gap acceptance is the inefficiency of Harders method in predicting appropriate critical gap values under mixed traffic conditions. The reason being the use of this method by previous researchers under uniform traffic conditions only. A paired sample t-test between critical gap values for Harders and “INAFOGA” method was performed to find out the difference in means of the values. The values were found to be 28-41% lesser as compared to the values obtained using form Satish et al “INAFOGA” method. Cluster diagrams plotted gives the comparison of critical gap values for the four different modes considered in this study for all the four sections.

7.1.2 Conclusions regarding the Comparison between Macroscopic Probability Equilibrium by Ning Wu and “INAFOGA” Methods

Basic statistics of the decision variables used for estimating critical gaps in this study are tabulated and two methods discussed in the available literatures are used to determine critical gaps of U-turn drivers at median openings. The first one is the “INAFOGA” method while the second one is “Macroscopic Probability Equilibrium Method”. A paired sample t-test between critical gap values for Probability Equilibrium and “INAFOGA” method was performed to find out the difference in means of the values. The negative t-statistic(-3.94004) and the two-tailed significance(0.00064 << 0.05) shows sufficient influence of parameters such as critical gaps, merging time, accepted and rejected gaps to compare these two methods. Radar plot illustrates the variation of critical gap values for the four different modes (4W, 2W, 3W and SUVs) considered in this study for all the six sections. It is clear from the radar plots that the critical gap values obtained using merging behaviour concept is higher than those values obtained using the Probability Equilibrium method by 18% to 31%. This difference is because of clear under-estimation of the critical gap values obtained by Probability Equilibrium method for U-turns. It can be admitted from these results that the probability equilibrium method does not take into account the unpredicted vehicular collaborations of non-motorized traffic with motorized ones under Indian mixed traffic conditions. Also, the Probability Equilibrium method was efficient in predicting U-turn Sport Utility Vehicle's gap acceptance for the section 2 (Rourkela) and 4(Bhubaneshwar). On contrary, Probability Equilibrium method is incapable in estimating the critical gap values under mixed traffic conditions for the other three modes. "INAFOGA" method on the other hand is found to be more suitable in addressing the traffic flow conditions for all the modes.

7.2 Conclusions regarding the t-statistics tests and One-way ANOVA tests for Significant Verification in Comparison in Statistical Package for Social Sciences (SPSS)

- Two paired sample T-statistic tests were performed : The first one being between Harders & INAFOGA method while the second one being between Macroscopic Probability Equilibrium & INAFOGA methods
- The first test conducted for a sample size of (154, 48 & 270) was efficient in determining the most efficient method among the two which was in this case INAFOGA method
- While the second one confirmed that critical gap values for Macroscopic Probability Equilibrium Method are about 18-31 % lesser than that obtained from INAFOGA
- The obvious conclusion for the results obtained from the second T-test was the greater manoeuvre/merging time for a 4 wheeler and its greater size over a standard 2 wheeler

- The obvious conclusion for the results of the first test is the efficiency of INAFOGA method in addressing mixed traffic conditions prevailing in India

- The One way ANOVA tests in IBM SPSS were conducted to test the possibility or significance of comparison between the existing methods used for estimating critical gaps in this study
- The results portrayed that indeed some of the methods like Probability Equilibrium , Modified Raff, INAFOGA & HARDERS can be compared while methods like Ashworth don't have any significant comparison at all

7.3 Conclusions regarding the Regression models/relationships between Critical Gaps and Traffic/Driver Behaviour related characteristics in OriginLab, SPSS and Excel

- With the increase in waiting time of a U-turn motorized vehicle near the close vicinity of /on the median opening for the selected sites, a power decay of critical gaps has been found out while analysing the driver behaviour characteristics with empirical equations and standardised co-efficient. The statement is followed by a deviation for four wheelers (Cars) including hatch-backs and sedans which showed exponential decay in critical gaps with increase in waiting time.

- For the second model, with increase in through/conflicting traffic volume there is an exponential decrease in critical gap values for U-turn drivers which in turn indicated that indeed critical gap for U-turns at median openings depend upon the quantity or volume of heavy vehicle proportions in the conflicting traffic flow.

- Going forward to the third model, through traffic plays a more vital role than U-turn flow or speed in determining a U-turn drivers gap acceptance characteristics and with increase in the speed (kmph) of through stream vehicles there is a substantial linear decrease in driver critical/accepted gaps.

7.3.1 Conclusions Regarding the ANOVA Power Regression Model

- Model illustrates the dependence of gaps accepted by a driver is indirectly proportional to the time required for merging of a U-turn vehicle
- Model verifies the fact that accepted gaps of a female driver is greater than that accepted by a male U-turn driver
- Conducting the ANOVA analysis it was found that there is a power regression (with R^2 = 0.832 & 0.945) dependence of merging time over accepted gaps for the opposite sexes

7.4 Discussions, Contributions and Applications

There is a clear short-coming of the existing methods like Modified Raff, Ashworth and Macroscopic Probability Equilibrium methods in addressing the complex behaviour of U-turn drivers at the selected median opening sections under mixed traffic conditions. This fact indulges us to conclude that there are obvious restraints in determination of capacity for a particular transportation facility. On a close look into the research area anyone can understand that the gap acceptance behaviour for U-turn vehicles at median openings have been neglected and majority of researches and traffic studies are being focussed on other un-interrupted and interrupted facilities consisting of intersections and, interchanges and roundabouts. In India, a place where various modes of traffic exists starting from non-motorized vehicles like hand-pulled/ Pedal-type rickshaws to large sized vehicles like cargo-trucks, Sport Utilities like Mahindra Bolero, very less attention is given to traffic rules. A death toll of over 100-500 persons occur every year due to cause of accidents. Traffic flow analysis of most of the urban transportation systems in India is one of the most challenging tasks in the history of traffic engineering. The methods applied for estimating critical gaps under such conditions can be used for any other transportation facilities. The following are the conclusions extracted after conducting the tenacious survey and study.

The research initiative introduces a new concept of "Merging Behaviour" of U-turn vehicles for necessary extraction of data for estimation of critical gaps under mixed traffic conditions. This new strategy utilised or introduced to the traffic engineers around the globe may emerge as a vibrant tool for determining capacity and as a guide for examining safety at un-signalised mid-block bi-directional median openings located in sub-urban areas of metro-cities. The term "Merging Time" indicates the time taken by U-turn vehicles to completely merge with the through/oncoming/conflicting traffic stream after completing their U-turn manoeuvres. The wide variety of motorized vehicles considered over the nine different median opening sections from the cities of Bhubaneshwar and Rourkela will definitely help understand the condition of traffic configuration in most of the parts of India. There was no difference in critical gap values between the two cities. Values were approximately the same with 0.5-1.0 second interval. The effectiveness of the "INAFOGA" concept in over-estimating correct critical gap values with respect to other existing methods like Macroscopic Probability Equilibrium and Harders indicated that existing methods still need to be calibrated to address heterogeneous traffic flow. "Waiting Time" of a U-turn driver at a median opening is the time lost by a driver in waiting for a suitable gap to merge/cross/conflict with the oncoming traffic flow. Waiting time is a behavioural entity and varies from driver to driver. The present study also modelled drivers waiting time with his critical accepted gap. The study certified that with increase in the driver waiting time there is a power or exponential decay in critical gaps accepted by the driver. Thus, stating critical gap also as a behavioural aspect. Another important factor in behavioural analysis is the effect of driver gender on accepted gaps and merging times. Analysing the selected median opening sections it was ascertained that female drivers accept gaps more lately than male ones. Also, the female drivers take longer time in completing the U-turn manoeuvres at median openings than male drivers. Regarding the same analysis, a power regression decay was obtained for the increase in accepted gaps with increase in merging times for both the sexes. Other traffic characteristics like conflicting traffic flow and speed have direct effect on gap acceptance and critical gaps of U-turn drivers at median openings. Empirical regression models between these conflicting traffic stream characteristics with the gap acceptance phenomenon (i.e. critical gaps) are developed. Models show that there is linearity between speed and critical gaps while power variation between flow and critical gaps which in turn indicates that both behavioural and traffic properties of vehicles and drivers affect driver gap acceptance grossly.

This new concept thus used for estimating U-turn critical gaps and evaluating driver gap acceptance have never been used previously and can be unpretentiously used by any traffic engineer/policy makers to address gap acceptance under mixed traffic conditions. Thus, all the aspects introduced through this study will definitely serve as a handy tool to improve traffic operations on unsignalized transportation facilities. However, there is still doubt about the utilization of the new concept of merging behaviour to other transportation facilities like roundabouts, interchanges, etc. and thus further research in this field is strongly recommended.

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APPENDICES

Appendix A

Table A.1 Detailed geometry of test sections

Sl #	# Lanes	Section Location	Geometry of median opening (m)						
			a	1	2	3	b	c	d
1	4 and 6-Lane Roads	Near Rourkela Institute of Management Studies – Rourkela, Odisha	9.6	3.3	3.3	3	1.3	2.4	14.8
2		Near Rainbow Software Training Complex on Panposh Road – Rourkela, Odisha	9.6	3.5	3.5	2.6	1.0	2.3	20.1
3		In front of Pal Height Mall (Towards Jaydev Bihar) – Bhubaneshwar, Odisha	9.75	3.4	3.4	2.9	1.2	2.1	20
4		In front of CS Pur HPCL petrol pump – Bhubaneshwar, Odisha	9.5	3.3	3.3	2.9	1.2	2.1	20.3
5		Near Patia IOCL petrol pump – Bhubaneshwar, Odisha	9.4	3.3	3.3	2.8	1.3	2.0	20.4
6		In front of Eastern Railway Headquarters, Bhubaneshwar	9.5	3.4	3.2	2.9	1.2	2.8	17.9
7		In front of SBI colony, Bhubaneshwar	9.4	3.1	3.5	2.8	1.3	2.2	15.3
8		Near Kalinga Stadium, Bhubaneshwar	9.5	3.3	3.4	2.8	1.0	1.6	15.7
9		In front of Regional College of Management, Bhubaneshwar	9.6	3.5	3.4	2.7	1.2	2.2	19.8

Table A.2 Observed traffic composition at different section

Sec #	2W		3W		CAR		SUV/MCV		LCV		HV		OTHER		Total		
	T	U	T	U	T	U	T	U	T	U	T	U	T	U	T	U	
1	2076 (47.6%)	492 (11.5%)	606 (13.9%)	72 (1.6%)	480 (10.9%)	246 (5.6%)	126 (2.9%)	36 (0.8%)	36 (0.8%)	24 (0.5%)	30 (0.7%)	6 (0.1%)	120 (2.7%)	18 (0.4%)	3474 (80%)	894 (20%)	4368
2	1821 (39.01%)	700 (14.99%)	420 (8.99%)	280 (5.99%)	514 (11.01%)	327 (7.00%)	94 (2.01%)	93 (1.99%)	70 (1.49%)	93 (1.99%)	46 (0.98%)	23 (0.49%)	121 (2.59%)	66 (1.41%)	3086 (66%)	1582 (34%)	4670
3	1756 (43.19%)	540 (13.28%)	300 (7.38%)	50 (1.23%)	542 (13.33%)	423 (10.40%)	102 (2.51%)	87 (2.14%)	70 (1.72%)	41 (1.01%)	33 (0.81%)	9 (0.22%)	78 (1.91%)	34 (0.83%)	2881 (71%)	1184 (29%)	4065
4	1776 (46.4%)	522 (13.6%)	522 (13.6%)	24 (0.6%)	534 (13.9%)	78 (2.0%)	120 (3.1%)	18 (0.5%)	42 (1.1%)	18 (0.5%)	26 (0.7%)	4 (0.1%)	22 (0.6%)	2 (0.05%)	3042 (82%)	666 (18%)	3708
5	2088 (47.7%)	552 (12.6%)	576 (13.1%)	72 (1.6%)	492 (11.2%)	170 (3.9%)	120 (2.7%)	80 (1.8%)	48 (1.1%)	30 (0.7%)	36 (0.8%)	12 (0.3%)	96 (2.2%)	8 (0.2%)	3456 (79%)	924 (21%)	4380
6	1398 (40.2%)	570 (16.4%)	504 (14.5%)	72 (2.0%)	468 (13.4%)	126 (3.7%)	138 (4.0%)	30 (0.9%)	36 (1.0%)	12 (0.3%)	48 (1.4%)	6 (0.2%)	60 (1.7%)	12 (0.3%)	2652 (73%)	828 (23%)	3480

7	1421 (46.52%)	472 (15.45%)	276 (9.03%)	41 (1.34%)	380 (12.44%)	94 (3.08%)	81 (2.65%)	24 (0.79%)	70 (2.29%)	41 (1.34%)	33 (1.08%)	9 (0.29%)	78 (2.55%)	34 (1.11%)	2339 (77%)	715 (23%)	3054
8	1547 (46.30%)	450 (14.13%)	276 (8.31%)	35 (1.05%)	560 (16.87%)	127 (3.82%)	114 (3.43%)	17 (0.51%)	77 (2.32%)	23 (0.69%)	27 (0.81%)	4 (0.12%)	51 (1.54%)	11 (0.33%)	2652 (80%)	667 (20%)	3319
9	1489 (40.94%)	357 (9.82%)	387 (10.64%)	75 (2.06%)	734 (20.18%)	123 (3.38%)	210 (5.77%)	24 (0.66%)	118 (3.24%)	21 ().58%)	39 (1.07%)	8 (0.22%)	42 (1.15%)	10 (0.27%)	3019 (83%)	667 (17%)	3637

The above tables A.1 and A.2 represented in Appendices gives a detail about the nine different median opening sections of median openings elaborately. The first table describes the detailed geometry of the median openings while the second table gives a brief review of the proportion of U-turning and through traffic vehicles corresponding to different categories of vehicles in details.

Table A.3 Critical Gap Distribution Table for estimation of Critical gaps by Macroscopic Probability Equilibrium Method by Ning Wu

						CAR					
All gaps(Tj)	A / R	Nr= Nr +1	Na=Na + 1	Fr = Nr/Nr,max	Fa = Na/Na,max	Ftc = Fa(t)/[Fa(t)+(1-Fr(t)]	Ptc = Ftc(j) - Ftc(j-1)	Td,j = [Tj + T(j-1)]/2	Ptc*Td,j	Ptc*Td,j^2	[Ptc*Td,j]^2
0.36	R	1	0	0.007	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.518	R	2	0	0.013	0.000	0.000	0.000	0.439	0.000	0.000	0.000
0.52	R	3	0	0.020	0.000	0.000	0.000	0.519	0.000	0.000	0.000
0.56	R	4	0	0.027	0.000	0.000	0.000	0.540	0.000	0.000	0.000
0.56	R	5	0	0.033	0.000	0.000	0.000	0.560	0.000	0.000	0.000
0.566	R	6	0	0.040	0.000	0.000	0.000	0.563	0.000	0.000	0.000
0.615	R	7	0	0.047	0.000	0.000	0.000	0.591	0.000	0.000	0.000
0.633	R	8	0	0.053	0.000	0.000	0.000	0.624	0.000	0.000	0.000
0.68	R	9	0	0.060	0.000	0.000	0.000	0.656	0.000	0.000	0.000
0.68	R	10	0	0.067	0.000	0.000	0.000	0.680	0.000	0.000	0.000
0.72	R	11	0	0.073	0.000	0.000	0.000	0.700	0.000	0.000	0.000
0.72	R	12	0	0.080	0.000	0.000	0.000	0.720	0.000	0.000	0.000
0.72	R	13	0	0.087	0.000	0.000	0.000	0.720	0.000	0.000	0.000
0.734	R	14	0	0.093	0.000	0.000	0.000	0.727	0.000	0.000	0.000
0.76	R	15	0	0.100	0.000	0.000	0.000	0.747	0.000	0.000	0.000
0.8	R	16	0	0.107	0.000	0.000	0.000	0.780	0.000	0.000	0.000
0.8	R	17	0	0.113	0.000	0.000	0.000	0.800	0.000	0.000	0.000
0.8	R	18	0	0.120	0.000	0.000	0.000	0.800	0.000	0.000	0.000
0.8	R	19	0	0.127	0.000	0.000	0.000	0.800	0.000	0.000	0.000
0.832	R	20	0	0.133	0.000	0.000	0.000	0.816	0.000	0.000	0.000
0.84	R	21	0	0.140	0.000	0.000	0.000	0.836	0.000	0.000	0.000
0.88	A	21	1	0.140	0.040	0.044	0.044	0.860	0.038	0.033	0.001
0.9	R	22	1	0.147	0.040	0.045	0.000	0.890	0.000	0.000	0.000
0.9	R	23	1	0.153	0.040	0.045	0.000	0.900	0.000	0.000	0.000
0.9	R	24	1	0.160	0.040	0.045	0.000	0.900	0.000	0.000	0.000
0.92	R	25	1	0.167	0.040	0.046	0.000	0.910	0.000	0.000	0.000
0.92	R	26	1	0.173	0.040	0.046	0.000	0.920	0.000	0.000	0.000
0.92	R	27	1	0.180	0.040	0.047	0.000	0.920	0.000	0.000	0.000
0.96	R	28	1	0.187	0.040	0.047	0.000	0.940	0.000	0.000	0.000
0.96	R	29	1	0.193	0.040	0.047	0.000	0.960	0.000	0.000	0.000
0.96	R	30	1	0.200	0.040	0.048	0.000	0.960	0.000	0.000	0.000
0.96	R	31	1	0.207	0.040	0.048	0.000	0.960	0.000	0.000	0.000
0.967	R	32	1	0.213	0.040	0.048	0.000	0.964	0.000	0.000	0.000
1	R	33	1	0.220	0.040	0.049	0.000	0.983	0.000	0.000	0.000
1	R	34	1	0.227	0.040	0.049	0.000	1.000	0.000	0.000	0.000
1	R	35	1	0.233	0.040	0.050	0.000	1.000	0.000	0.000	0.000
1.003	R	36	1	0.240	0.040	0.050	0.000	1.002	0.000	0.000	0.000
1.04	R	37	1	0.247	0.040	0.050	0.000	1.022	0.000	0.000	0.000
1.067	R	38	1	0.253	0.040	0.051	0.000	1.054	0.000	0.000	0.000